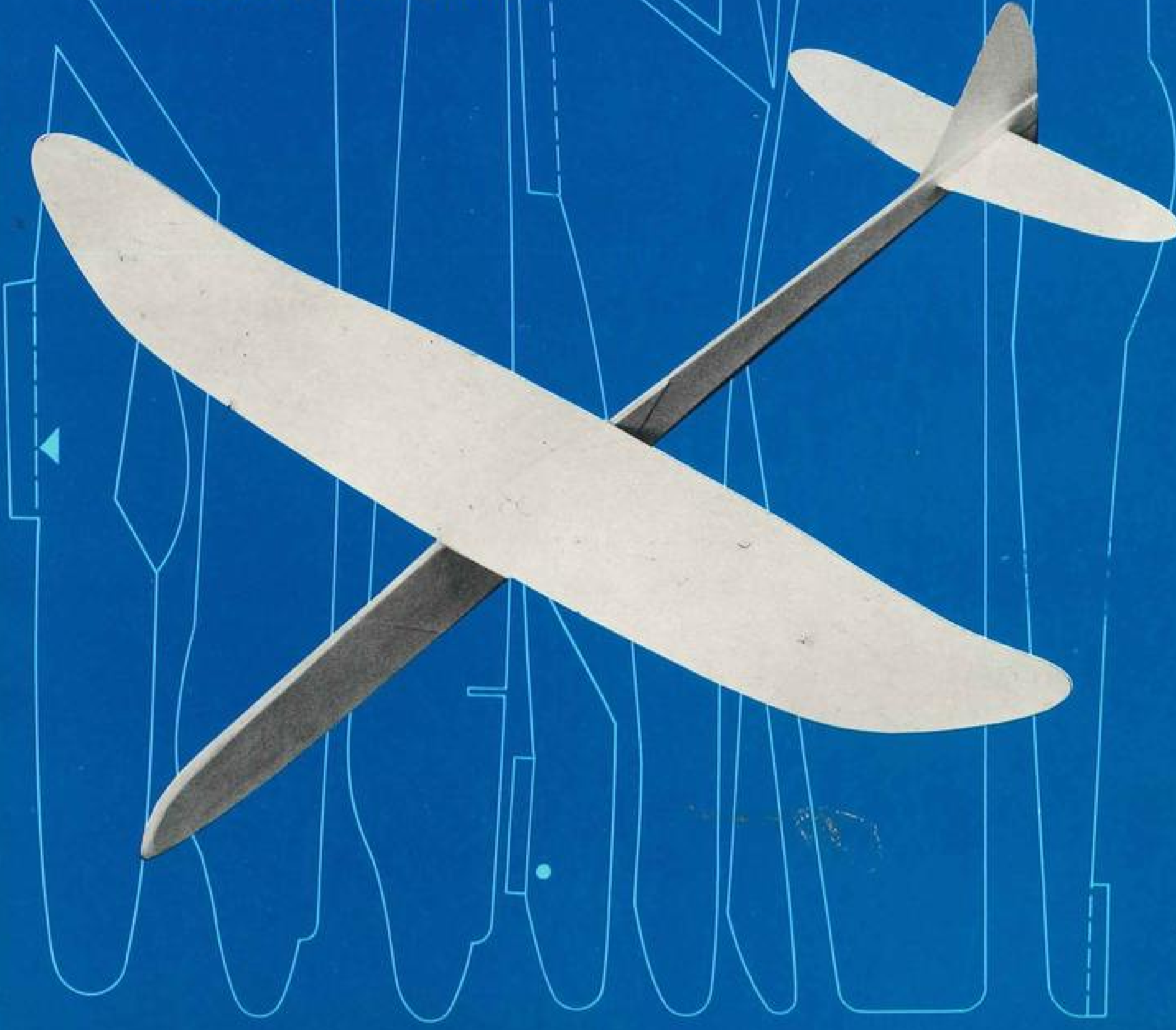
# COLLECTION OF PAPER AIRPLANE PLANS

YASUAKI NINOMIYA



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# Preface

Probably all of you have folded paper airplanes. In fact, it would be no exaggeration to say that interest in aviation often originates with one's first paper plane.

In contrast to model airplanes, which employ wood, balsa, bamboo, plastics, paper, and aluminum, paper craft use practically nothing but paper. A quick rundown of the characteristics of paper as a model-airplane material will quickly convince you of its superiority.

We will make good use of paper's distinctive features in our models, but instead of trying for solid or plastic models that look like real airplanes down to the last detail, we will put paper's lightness and beauty to use to create model planes that are both pleasing to see and sound in actual flight.

One of our problems will be to make our paper planes suit the special circumstances under which we use them. Designs in real airplanes vary according to the use of the plane: passenger, military, experimental, etc. Paper planes, too, must conform to certain exterior factors. First of all, we throw them with considerable force. Secondly, when they land, they bump into the surface of the floor or ground over and over again. Furthermore, since they are small and low speed, they have to fly according to the aerodynamic characteristics of such aircraft. Clearly, to fulfill these requirements, our paper models must be more than mere copies of real airplanes.

Our most important aviation design points must be lightness and strength. In the models in this book, the following usually holds true: the wings are thin, curved, and reinforced at the central section. The fuselage consists of a number of sheets of paper glued together. The number of sheets is greater at the nose, where strength is essential, and decreases toward the tail section. A construction of this sort has much to recommend it. It is easier to make than monocoque construction. It is strong on impact. It is easy to hold in the fingers. It is easy to repair. It causes very little fuselage parasite drag.

The book contains plenty of different airframe forms including origami planes, trainers, racers, profile models, creative craft, and modification planes. Start with the ones you like best. There are separate reference sections on principles of aviation, adjustments, and methods of sending your craft aloft.

Make plenty of paper aircraft. You will enjoy just looking at them, but you will have an even better time putting them into graceful flight.

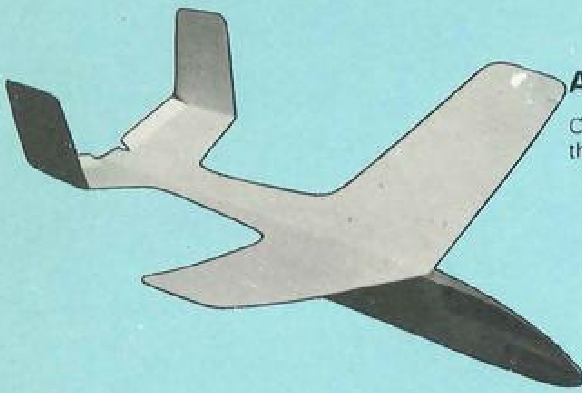
Yasuaki Ninomiya

March, 1968

# Contents

# Cutout Aircraft

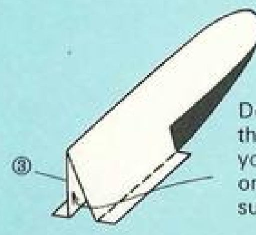
Usually, with aircraft that require a lot of gluing, you have to wait a long time for them to dry. Here is an easy plane with few parts and very few places to glue. Be sure that you fold accurately to the middle line and make the plane just as shown or it will not fly as straight as it should. Another piece of advise: fly it only indoors because its airframe is small and it is light.



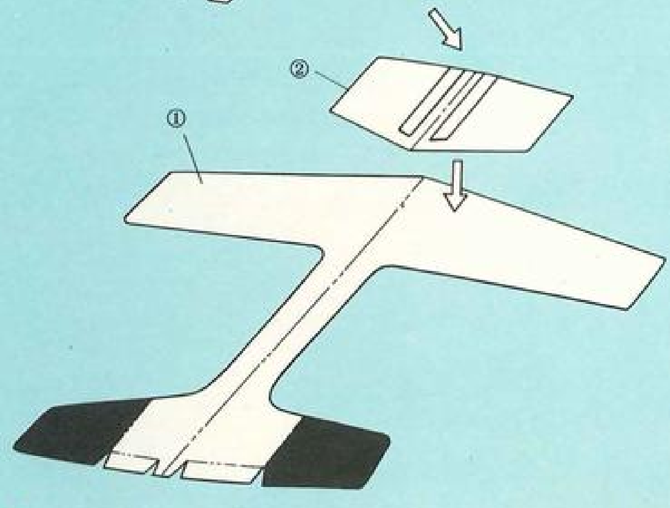
## ASSEMBLY

Cut out the parts, and glue them together as shown below. Note that the aircraft is shown in an upside-down position.

Glue ① and ② together. Fold slightly along the center line. Glue ③ to the spots shown on ②.

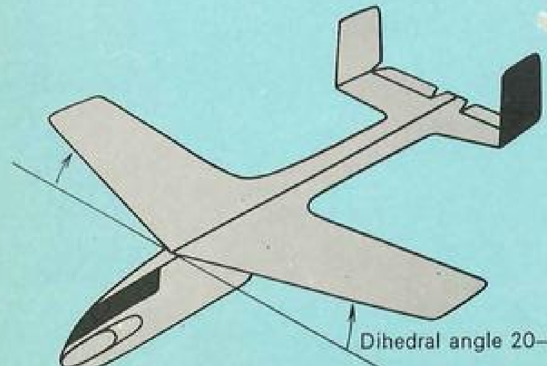



Do not glue the inner surfaces of the nose section together. When you glue it to the spots indicated on the main wings, these two surfaces should be slightly open.



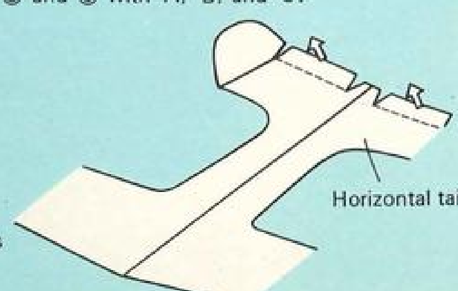

## ADJUSTMENTS

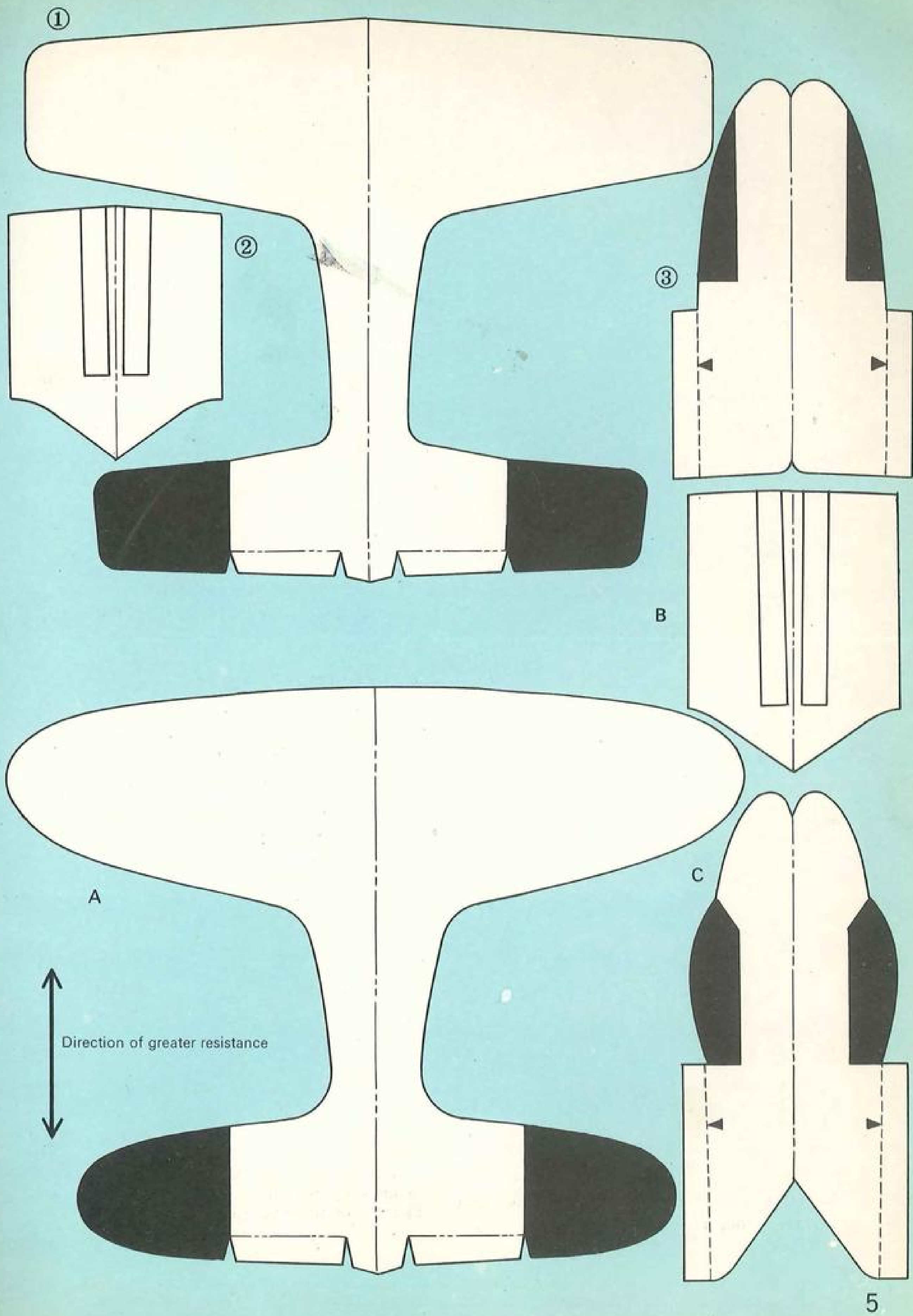
1. Fold along the center line so that the main wings rise at an angle of from 20 to 25 degrees.
2. Cut and bend the vertical tail planes.
3. Fold the trailing edges of the horizontal tail planes up along the dotted lines.
4. Add a couple of paper clips to the nose to bring the airframe's center of gravity to the place marked ▲.
5. Before you fly it, look at the plane from the front, and correct any warp in the wings or fuselage.




Be sure you have not glued the inner surfaces of the nose section together. Leaving them apart makes a stronger airframe.

Join ①, ② and ③ with A, B, and C.





①
②
③
B
A
C
Direction of greater resistance

# Materials

### Paper
Use thickish drawing paper or Kent drafting paper, except in origami planes, where you will need a thin paper.

### Paper clips
Ordinary bent-wire paper clips are fine for weighting the nose. Use lead foil, like that used for fishing tackle, when you need to insert the weight in the fuselage.

### Adhesive
Fast-drying adhesives—of the cellulose types—are best because they contain no water. Water-soluble adhesives cause the paper to wrinkle. Avoid them.

### Paints
Avoid heavy paints that weight the plane down. I recommend thin coats of clear iacquer because it is easy to clean should dirt stick to it. Water paints, like water-soluble adhesives, wrinkle the paper.

### Tools
Pencils, sharp scissors, knife, and tracing paper for transferring patterns.

# Transferring Patterns

There are 20 paper aircraft patterns in this book which you will have to transfer to your drawing or Kent paper. You may think this is a lot of trouble, but I shall let you in on two or three ways to do it that will make your task lighter.

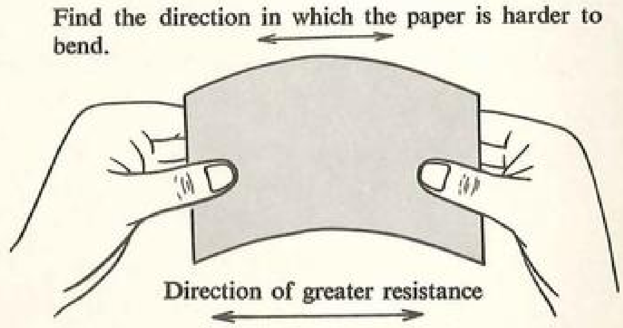
I know I said in the preface that you did not have to worry about direction in paper, but the truth is that paper does have a horizontal and a vertical grain and that one of these is a little easier to bend than the other. In transferring patterns, always be sure that the wing-span direction and the length of the fuselage lie along the paper grain that resists bending. This will make your airframe stronger.

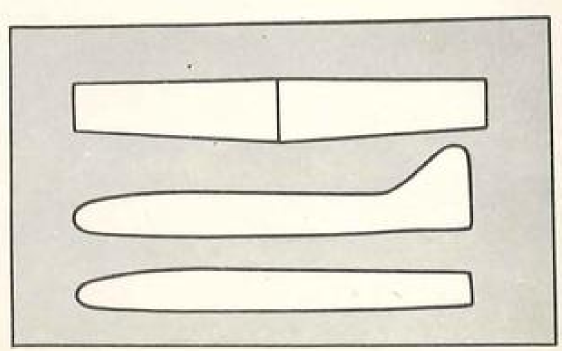
### Transferring Patterns
(1) Put your sheet of drawing or Kent paper under the page with the pattern and push a needle through from above along the pattern lines to make marks in the paper below. Take the drawing paper out, connect the pin marks with a pencil line, and reproduce the chart of the aircraft.

(2) Use thin tracing paper on top of the pattern, and draw the chart. Glue the tracing paper to the drawing paper or Kent paper you intend to use, and cut them both at the same time. Put your glue only around the outside of the chart you drew on the tracing paper. Do not glue the entire surface.

(3) If you are going to make several of the same airplane, trace the pattern from the book with tracing paper. Select a piece of thick cardboard, glue the whole piece of tracing paper down flat on the cardboard, and wait for it to dry. When it has, cut out patterns which you can later use to draw the parts you need as many times as you need them. Always use a well sharpened pencil.

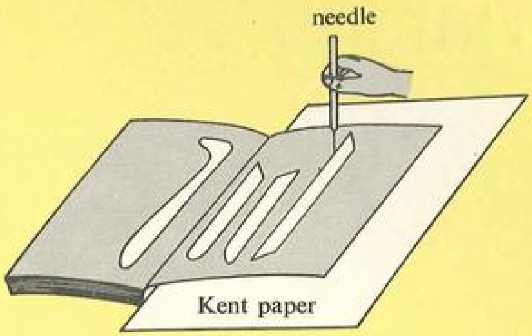
Find the direction in which the paper is harder to bend.

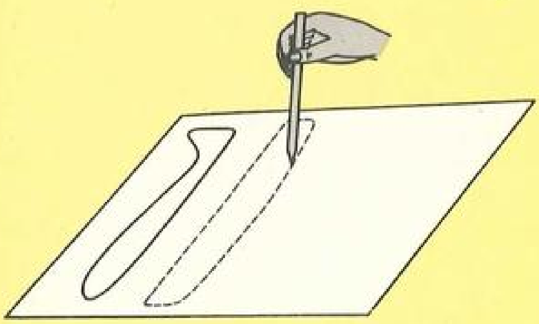


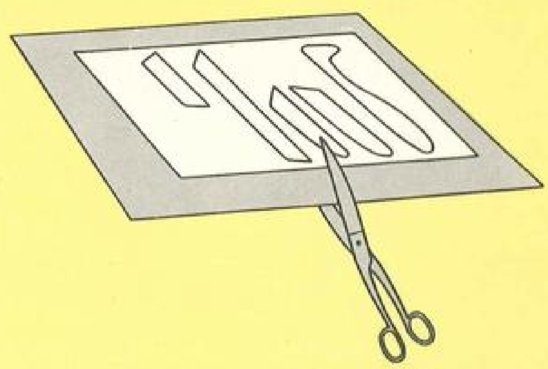
Arrange for the length of the fuselage and the span of the wings to agree in direction with the paper's direction of maximum resistance to bending.

①



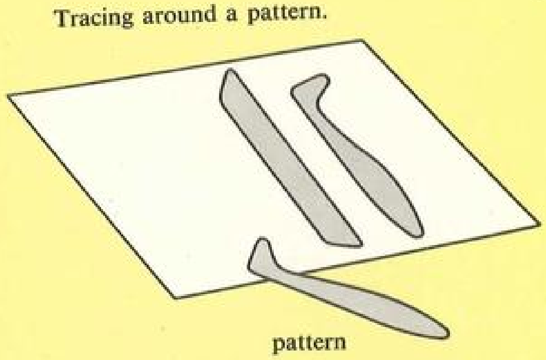
②



Apply the glue in areas outside the airframe parts.

③

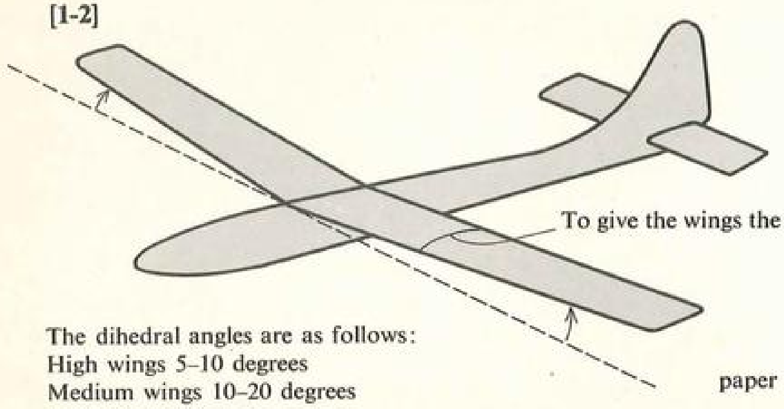
Tracing around a pattern.



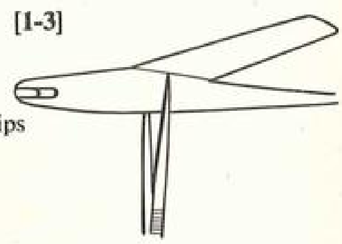
# Adjustments and Flying

[1-1]

[1-2]




[1-3]




The dihedral angles are as follows:
High wings 5–10 degrees
Medium wings 10–20 degrees
Low wings 20–25 degrees
Reduce these angles for craft with sweptback wings.

## Adjustments

Before you make any adjustments or do anything at all, make sure your craft is thoroughly dry. Even when you use fast-drying cements, the several layers you need take some time to dry. All you can do is be patient. If you attempt to fly or adjust your plane before it dries, not only will it be too weak structurally to function well, the moist adhesives will possibly cause the center of gravity to shift.

When it is thoroughly dry, first hold it in your hand, and examine it from the front. Correct any twists or warps in the fuselage and wings (fig. 1–1). Next, very carefully put into the wings the camber you see in fig. 1–2. Finally, following the instructions that accompany the individual aircraft pattern, give the wings the suitable dihedral angle.

When you have done all this, add sufficient paper clips to make the center of gravity of your craft agree in position with the black arrow on the pattern. If you are using lead foil in the nose, adjust the amount. If you hold the plane with tweezers (fig. 1–3) you will easily see where the center of gravity is.

If you have designed the plane yourself, following the instructions in fig. 2–18, work out your plane's mean aerodynamic chord length, and align the center of gravity with a point from 25 to 30 percent of the chord length from the leading edge.

Now let's make adjustments in accordance with flight observations. Hold your craft as you see in fig. 1–4, and throw it gently in a place where no wind is blowing. Aim it slightly down. If it glides smoothly, as the plane in fig. 1–5 b, all is well. If it stalls, as in 1–5 a or crashes as in 1–5 c, make the indicated corrections in the attack angle of the horizontal tail planes.

When you throw the craft straight ahead, should it swerve either to the right or the left (fig. 1–6) the wings, fuselage, or vertical tail plane are out of line. Correct them.

If you perform these tests indoors, you will find that throwing your craft into curtains provides a cushioning effect that softens the plane's fall and prevents damage.

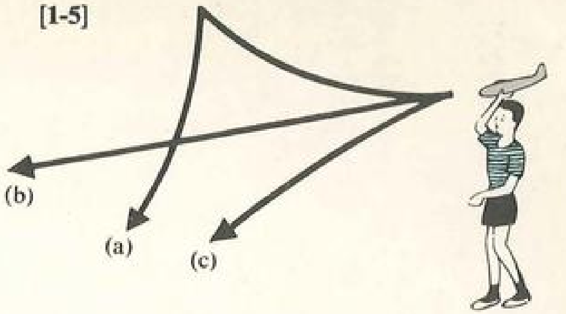
## Flying

Here are some tips on flying your craft when you put plenty of force into the throw. If you throw straight ahead and up, the craft will swerve up then fall and lose a good bit of altitude. Be sure that beforehand you put the slight bend in the wings and vertical tail plane that you used in quiet flights (figs. 1–5 and 1–6). When you are flying your craft out of doors, adjust it to spiral left, hold it in your right hand, incline it to the right, and throw it with all your might diagonally right and up. The craft will gain altitude as it slowly spirals right, then it will spiral left and go into the glide.

In these cases, you can hold the craft as you see in fig. 1–4 or as you see in fig. 1–7. Choose the method that is more comfortable.

For planes with sweptback or delta wings, you will find that the flying method shown in 1–5 c, or something close to it, will prevent wingtip stalling.

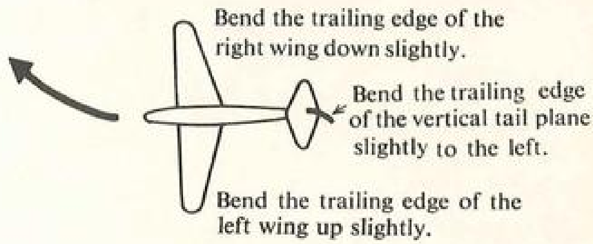
**[1-5]**




(a) Bend the trailing edges of the horizontal tail planes down slightly.
(b) Just right; no corrections.
(c) Bend the trailing edges of the horizontal tail planes up slightly.

**[1-6]**

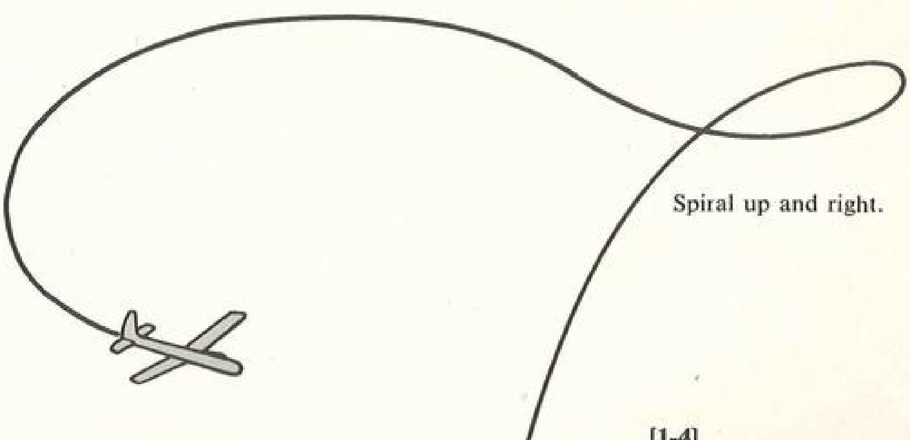
Corrections for craft that veer to the right




The corrections are just the reverse for craft that veer to the left.

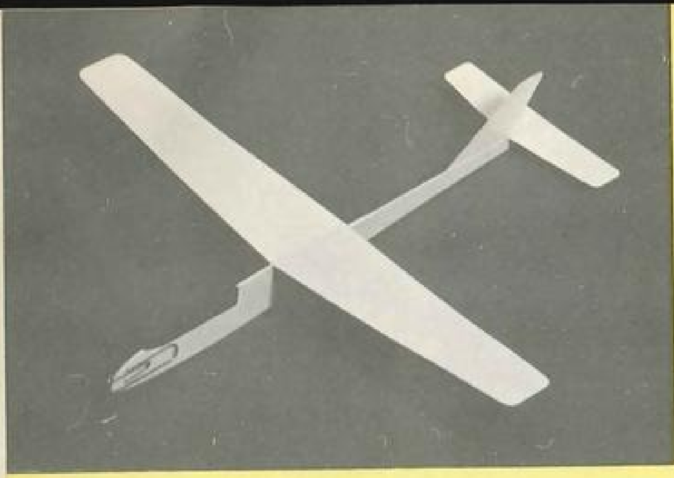
**[1-8]**

Incline the airframe to the right slightly, and throw it diagonally right and upward. (Left-handed people reverse the directions.)



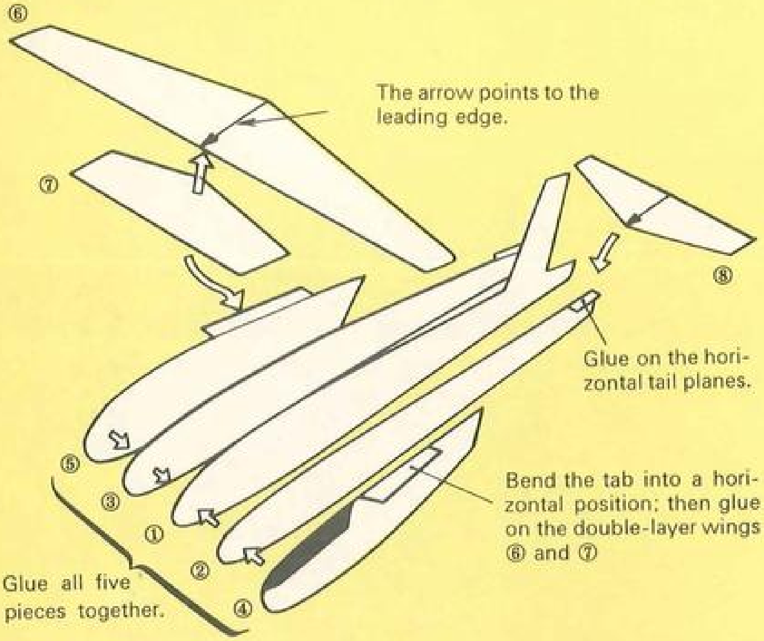

**[1-7]**

**[1-4]**



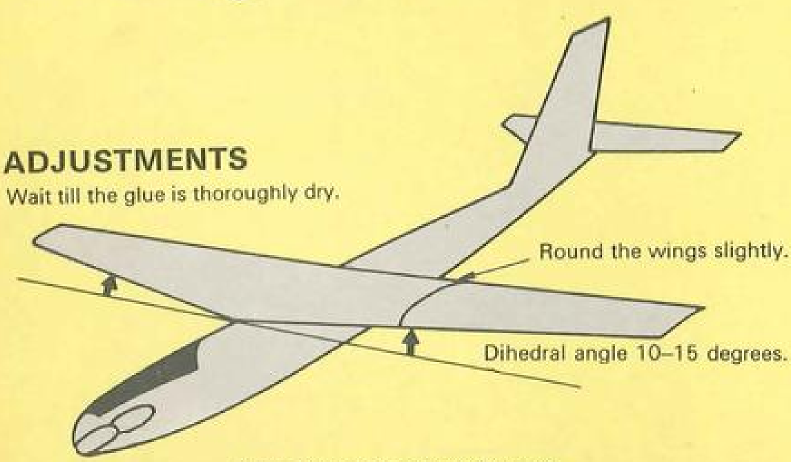
# Trainer

## ASSEMBLY



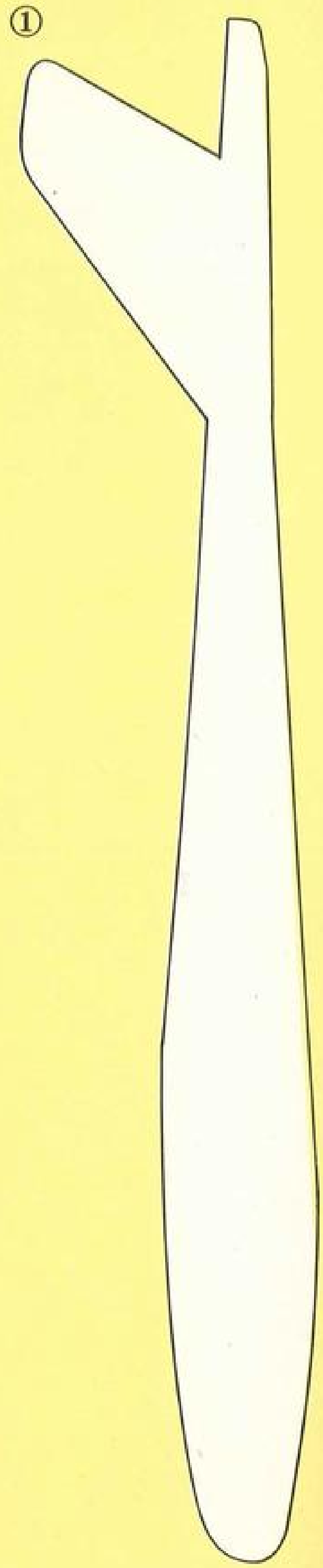

## ADJUSTMENTS

Wait till the glue is thoroughly dry.




Add a few paper clips to the nose to bring the center of gravity to the place marked ▲.

①



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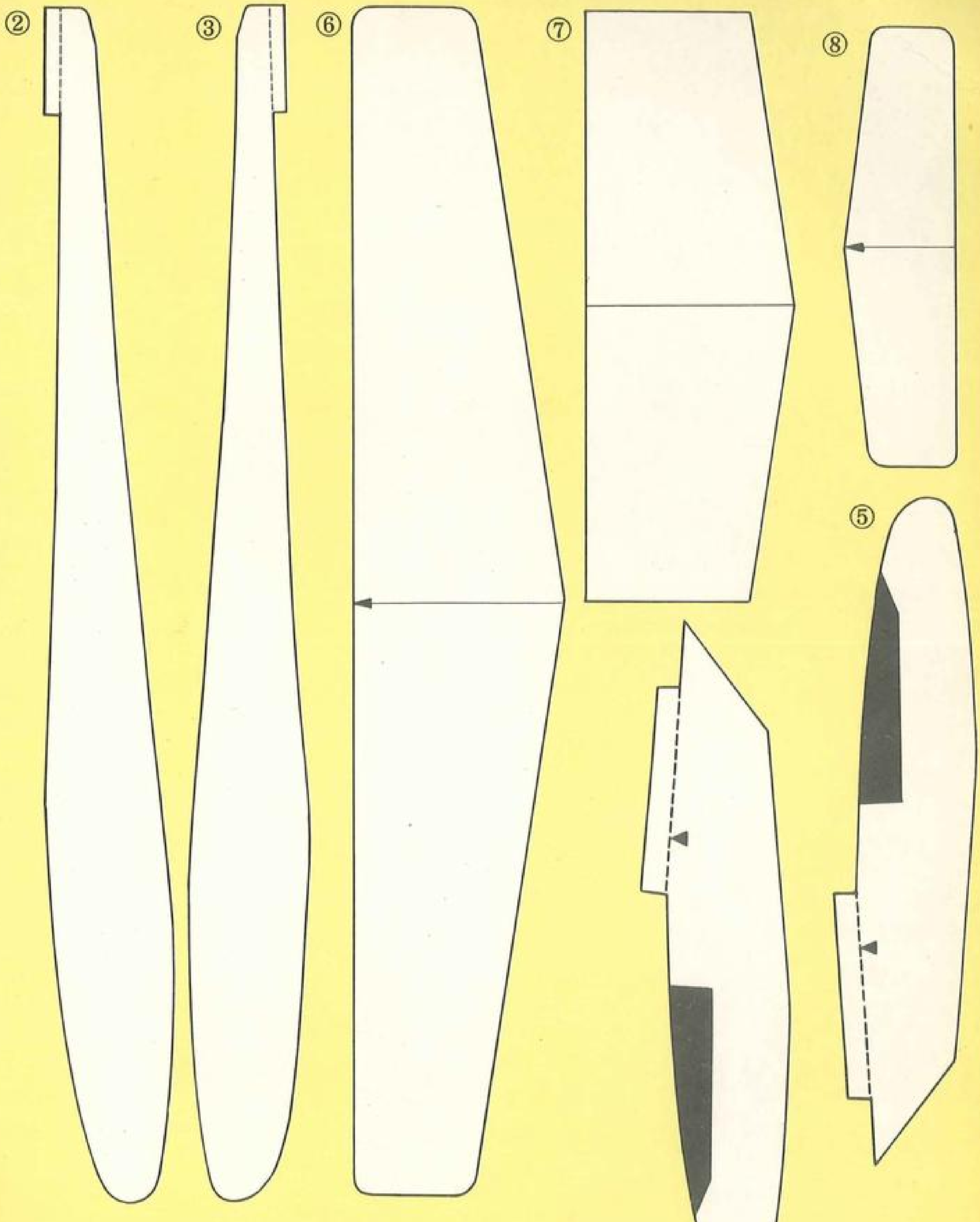
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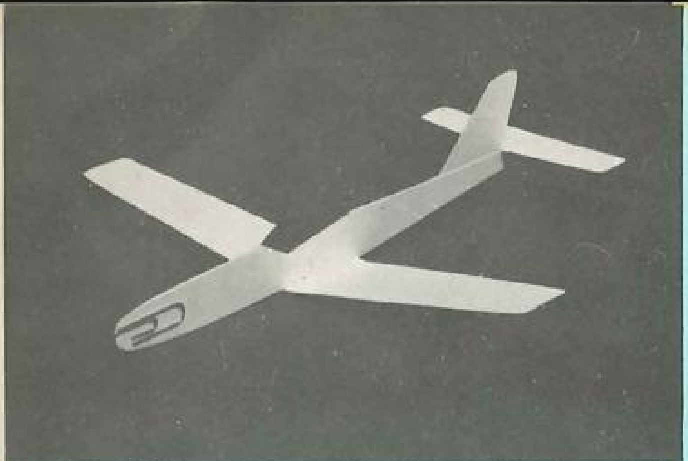
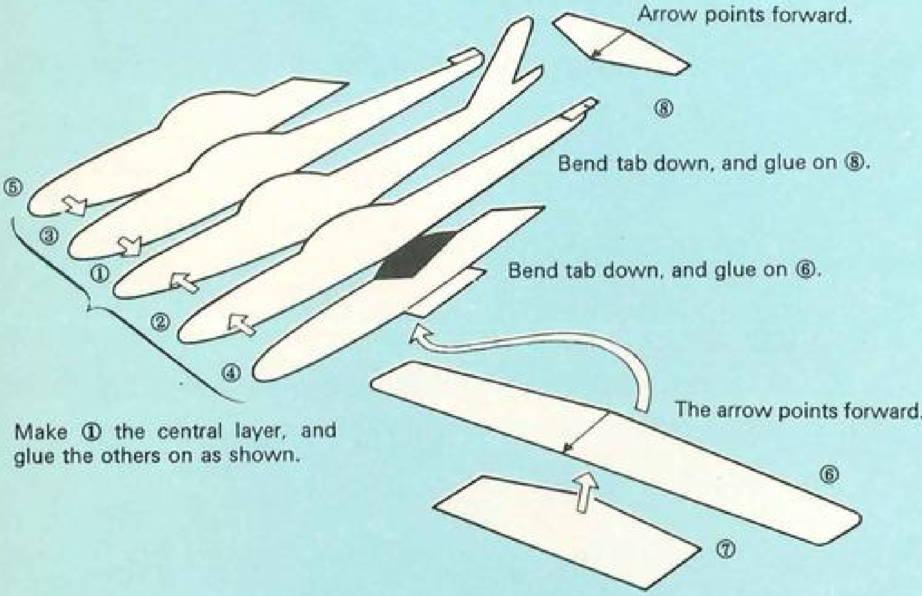


# Low-wing Trainer

## ASSEMBLY

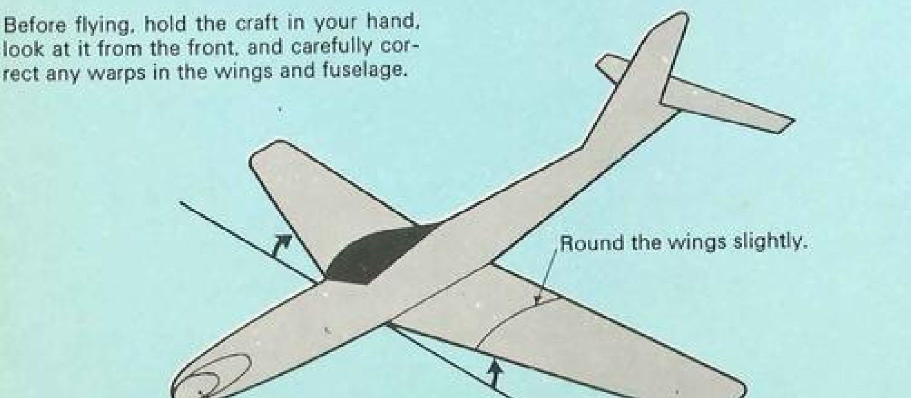


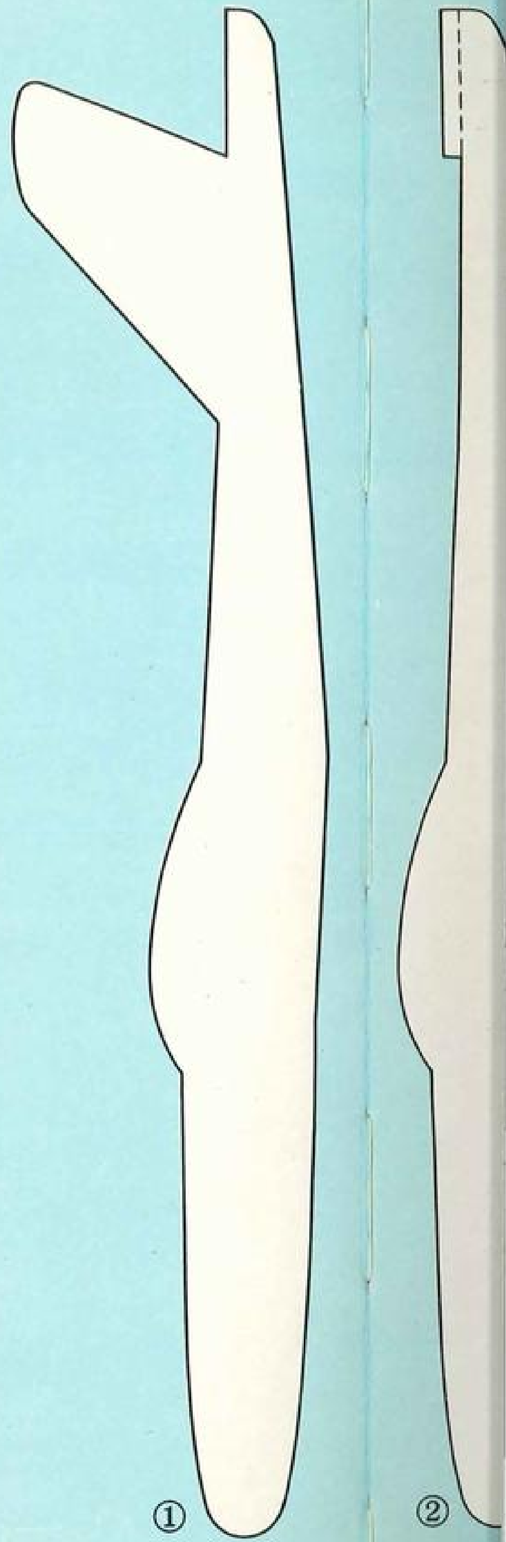

Make ① the central layer, and glue the others on as shown.

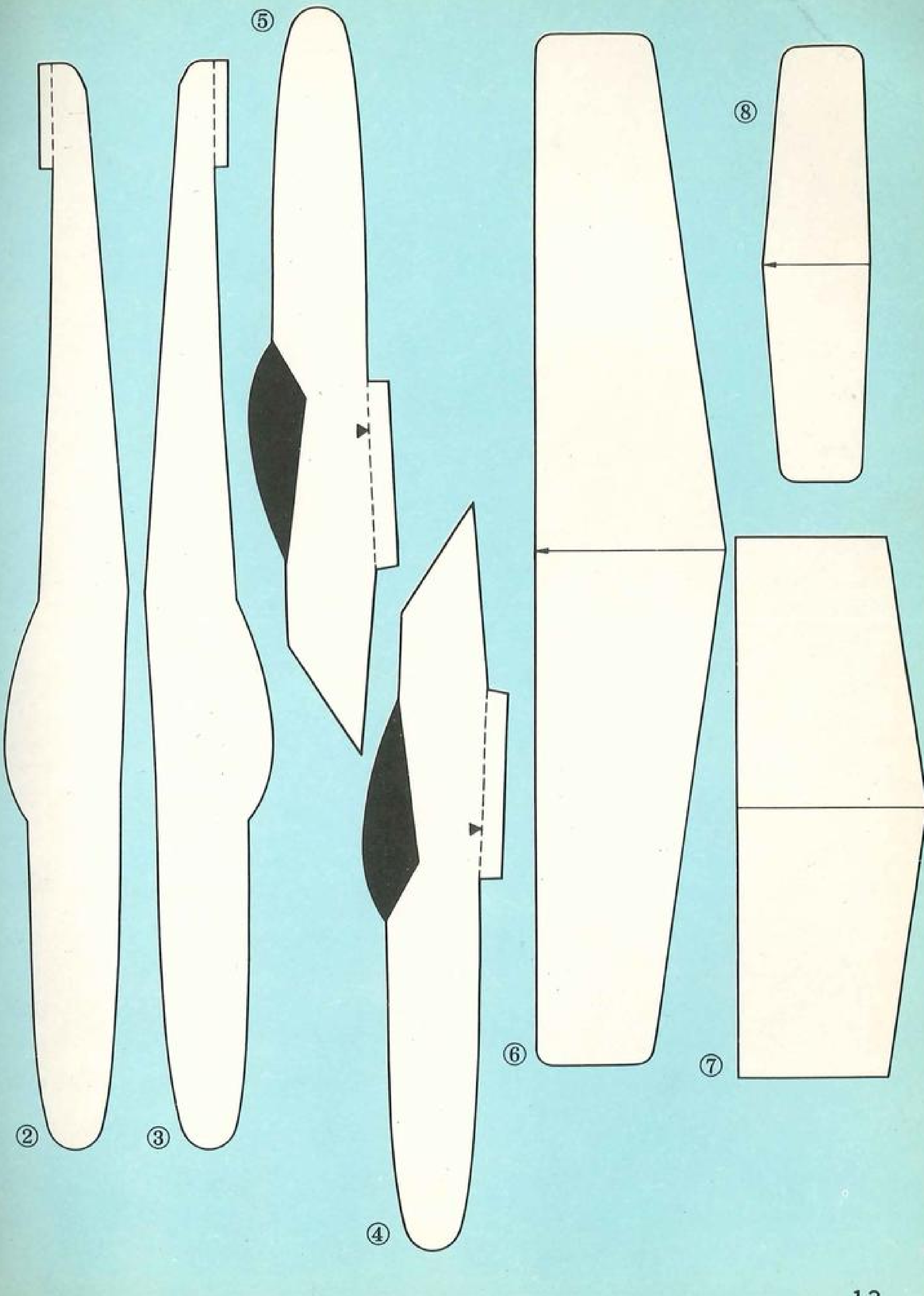
## ADJUSTMENTS

Wait till the glue is thoroughly dry.

Before flying, hold the craft in your hand, look at it from the front, and carefully correct any warps in the wings and fuselage.

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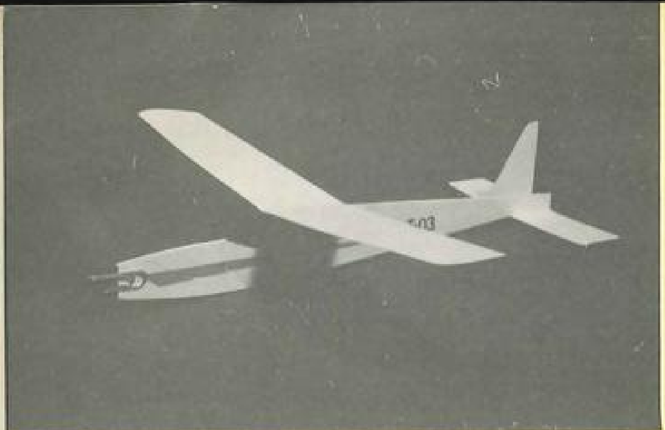
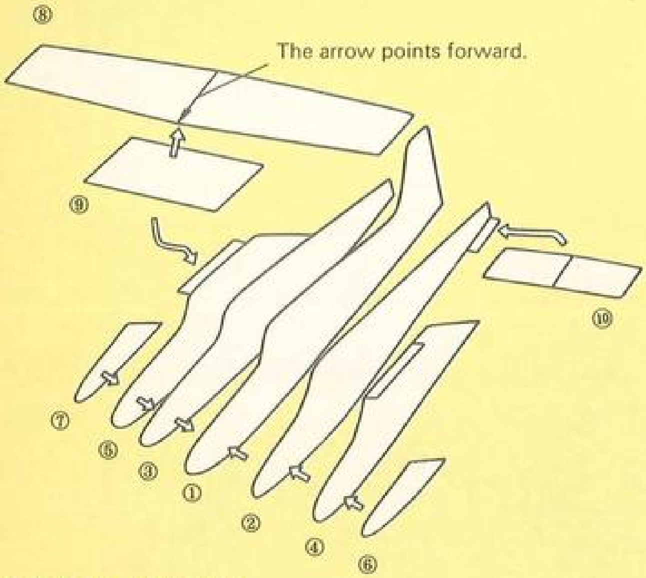


# High-wing Trainer

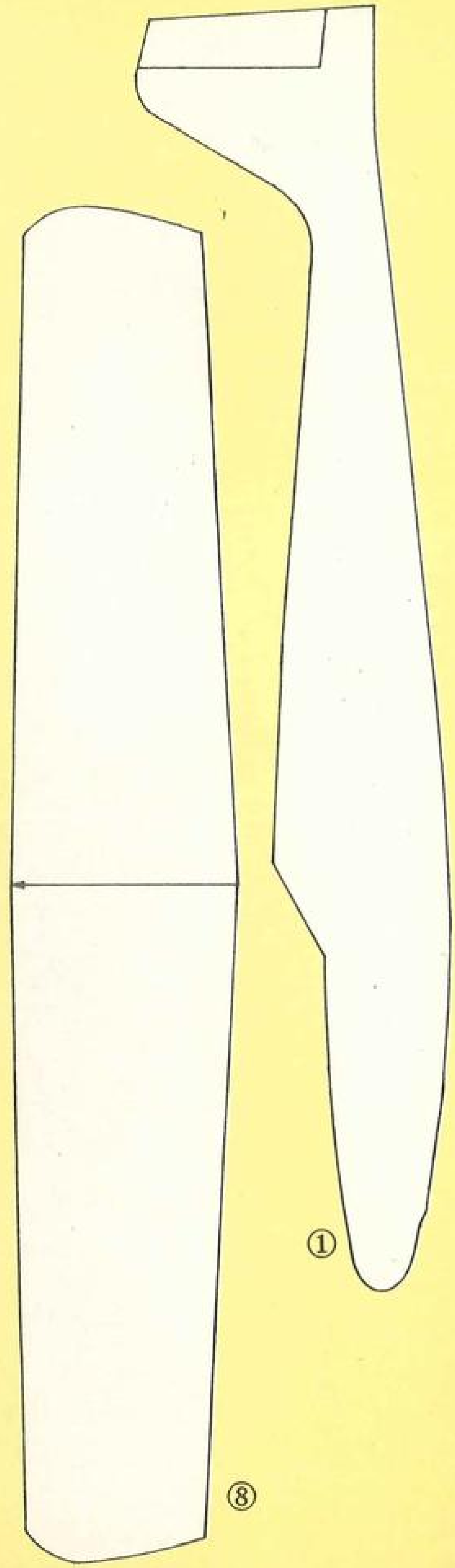
## ASSEMBLY

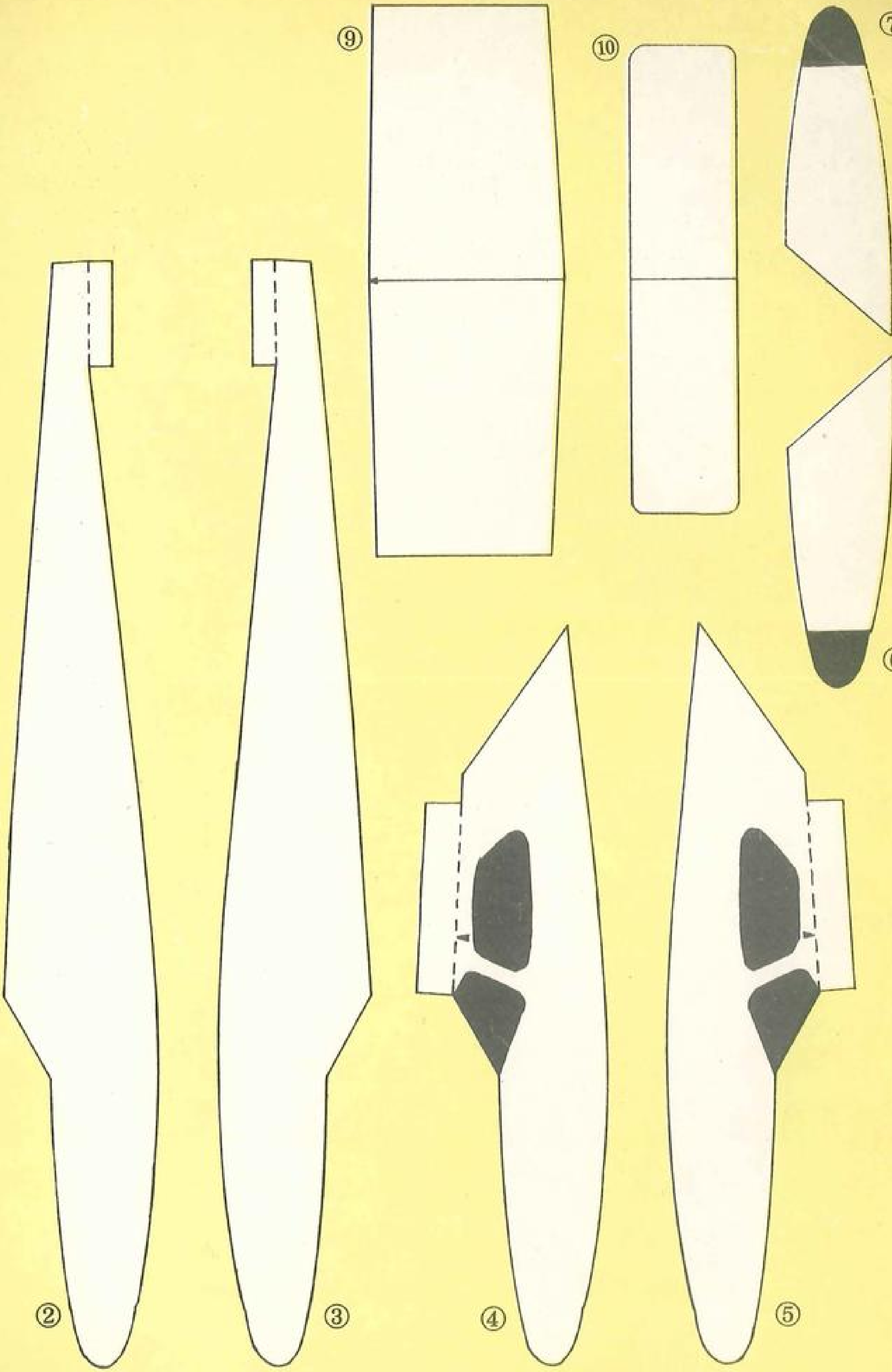
Glue ⑨ to the underside of the main wings.




## ADJUSTMENTS

Wait till the glue is thoroughly dry.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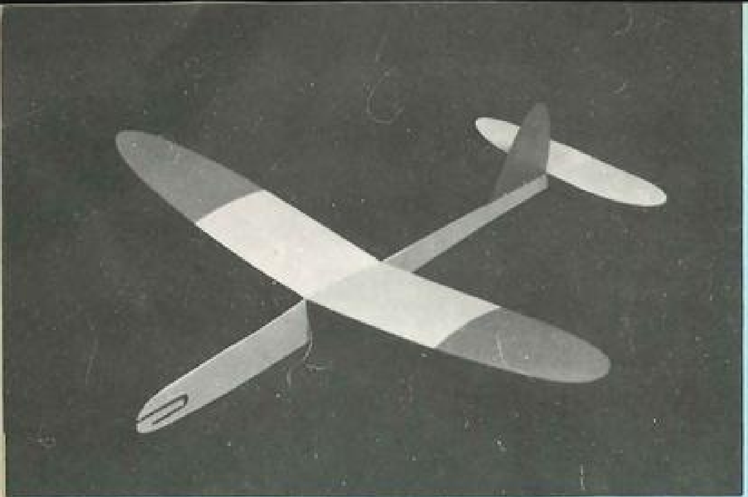
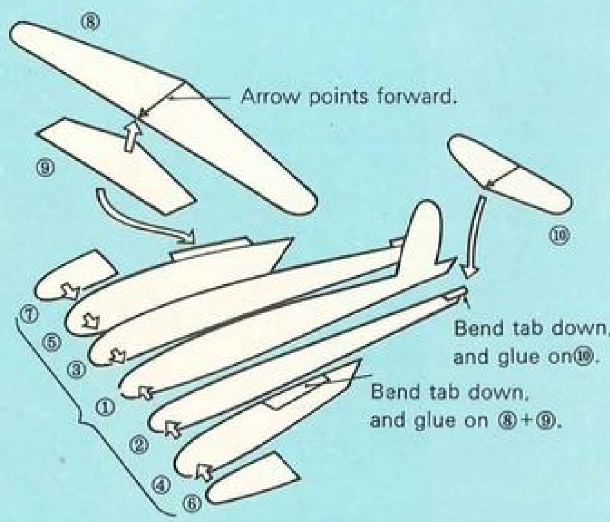
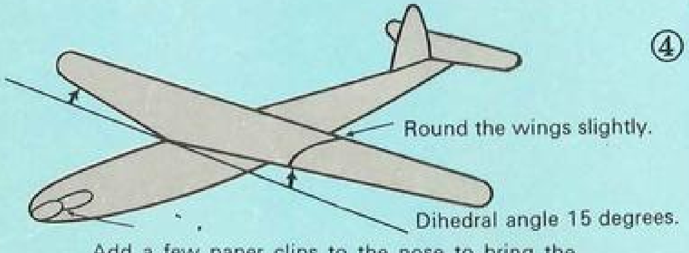


# Racer

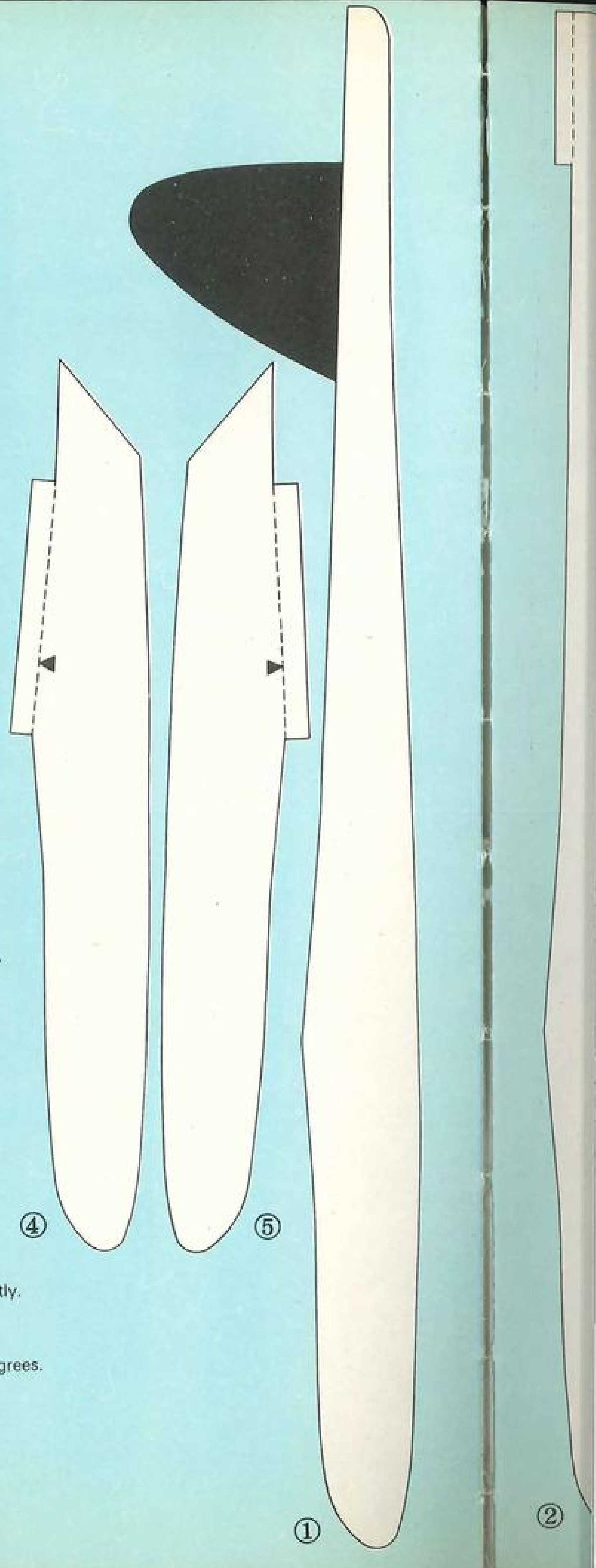
## ASSEMBLY

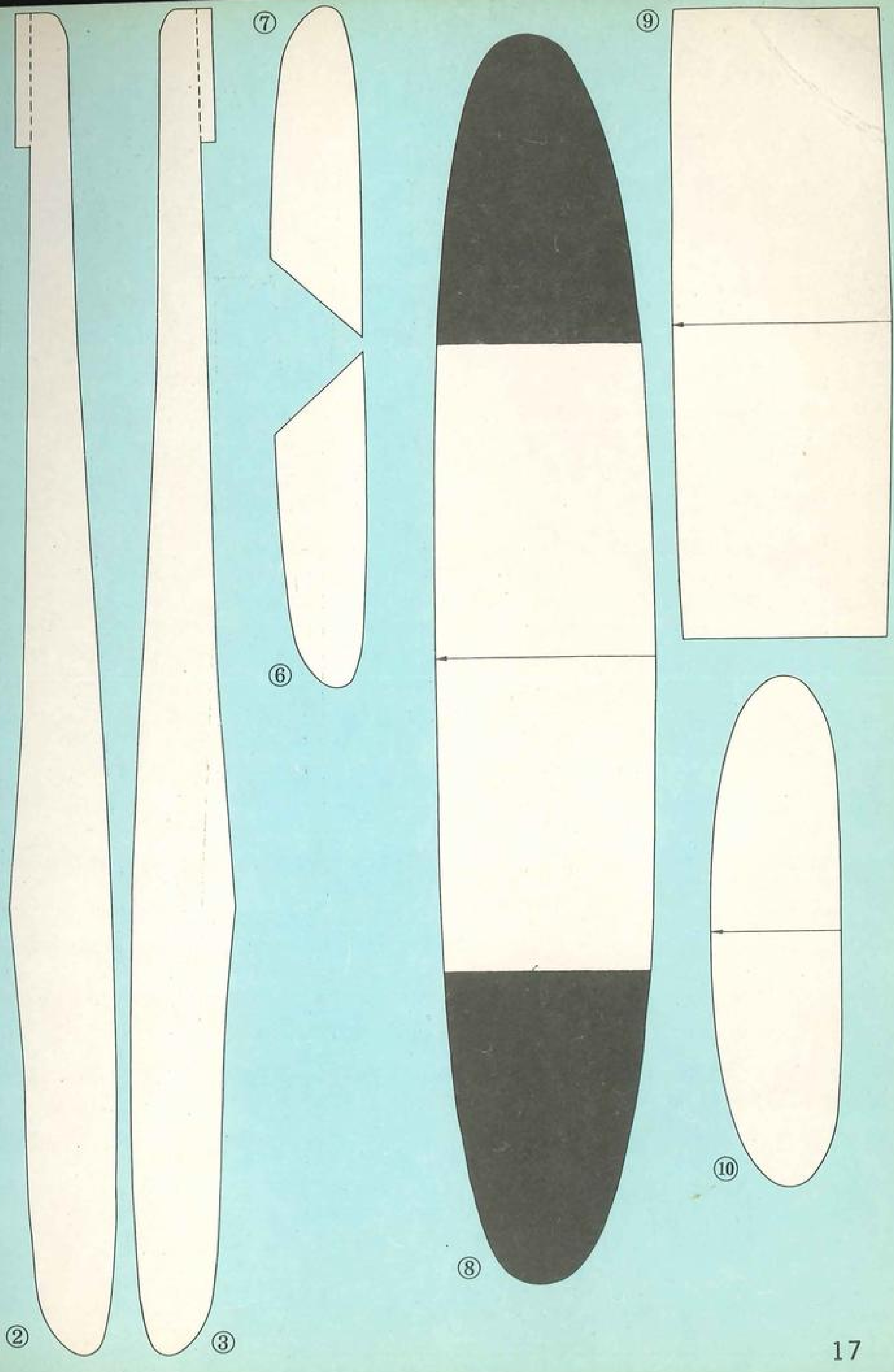



## ADJUSTMENTS




Add a few paper clips to the nose to bring the center of gravity to the place marked ▲.

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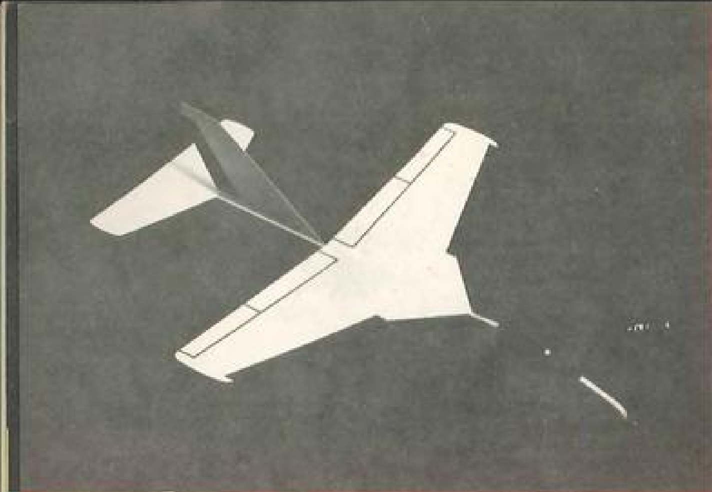
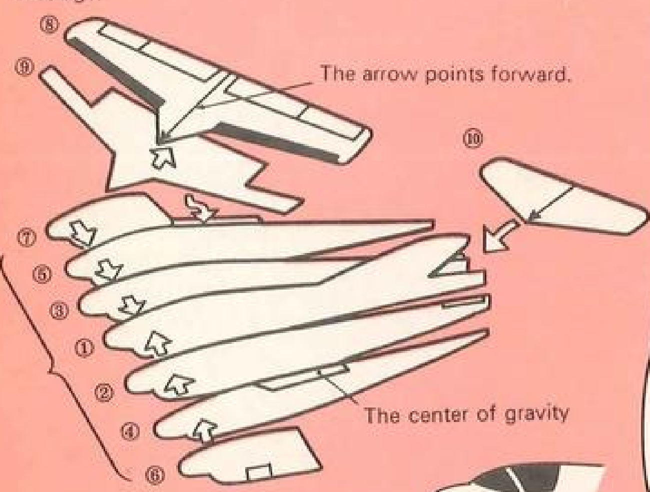


# LTV A7—Corsair II

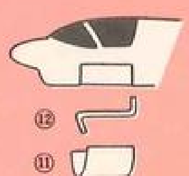
This version of the Corsair II differs somewhat in configuration from the real plane. The sweep back in the wings is less so that the plane will fly better. This is an easy to make, easy to hold, and easy to fly paper version.

## ASSEMBLY

Glue reinforcement ⑨ to the underside of main wings ⑧, next add the completed wings to the fuselage.




Glue the fuselage parts together.

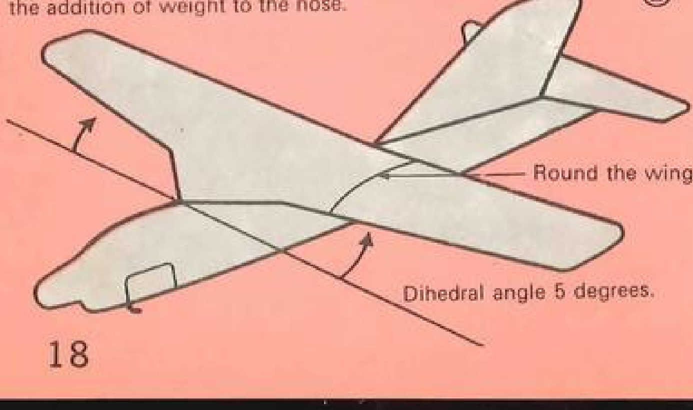


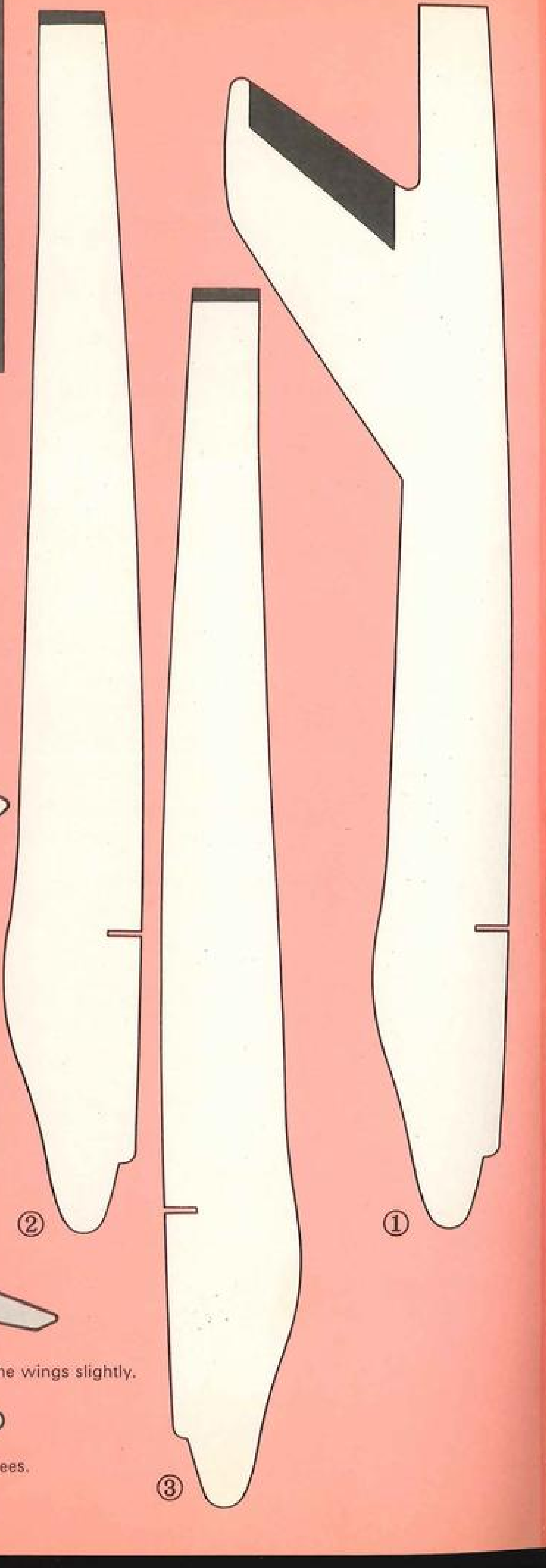

## ADJUSTMENTS

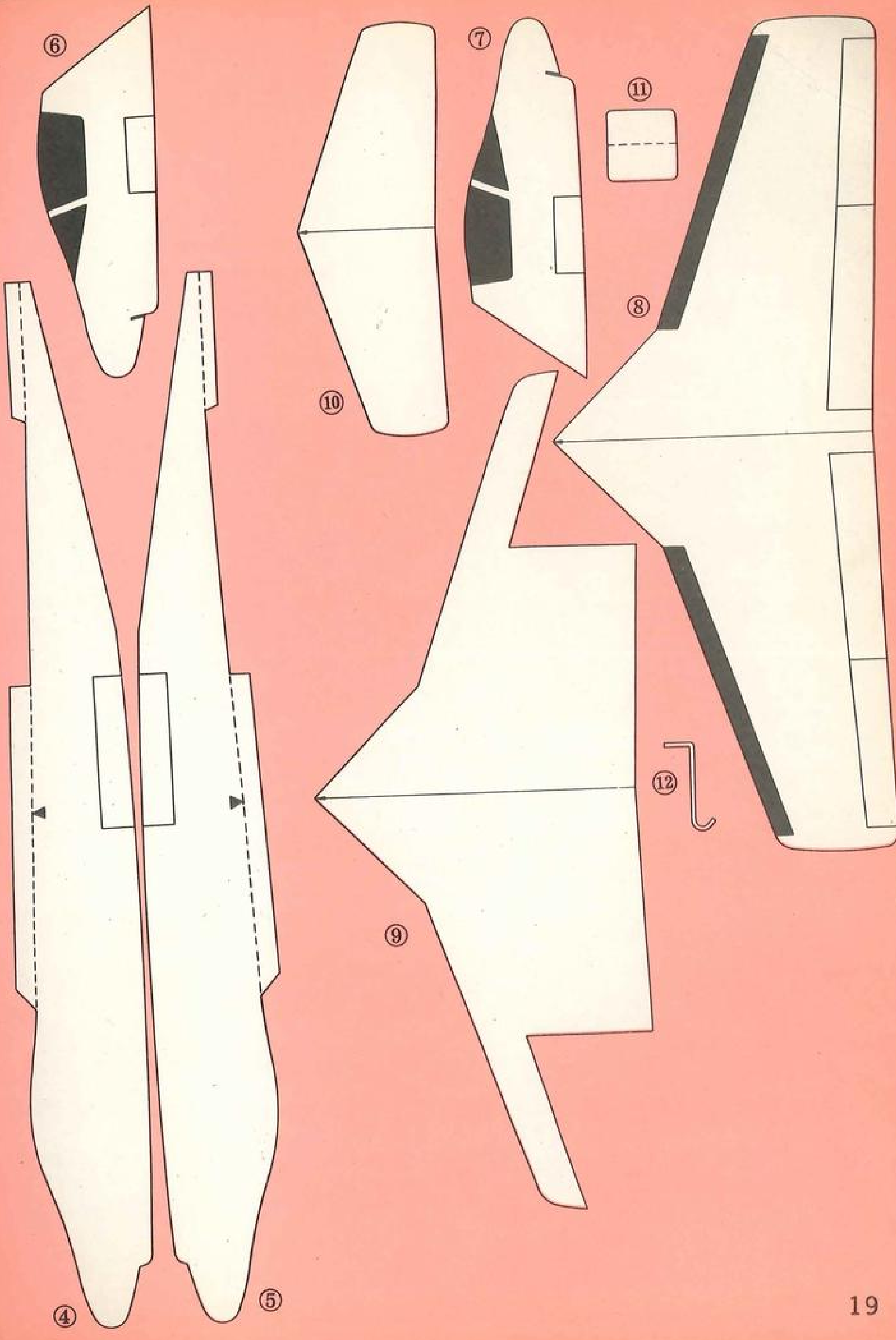
Wait till the glue is thoroughly dry.

Looking at the craft from the front; correct any warp in the wings and fuselage.

The center of gravity should fall in the right place without the addition of weight to the nose.

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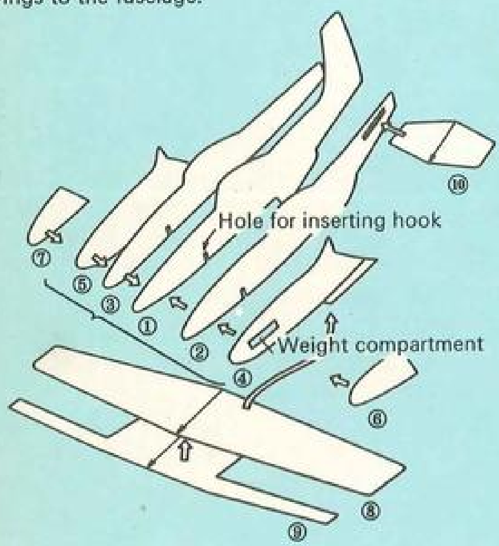
# North-American P-51 —Mustang

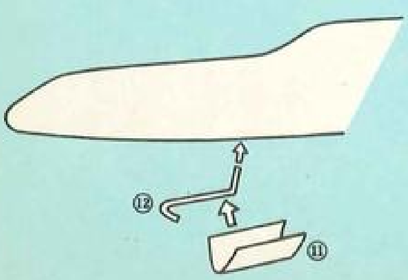
## ASSEMBLY

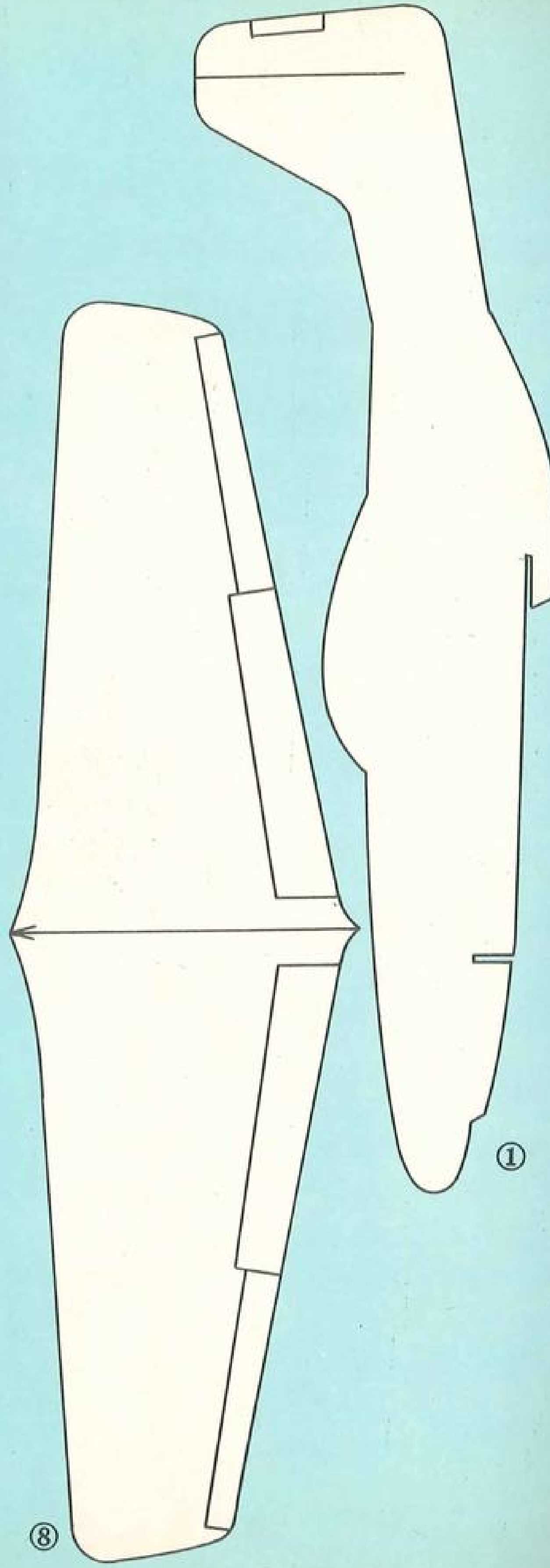
Glue parts ① through ⑥ together; let them dry. Carefully cut the compartment for the lead foil weight in the nose and the slit for the horizontal tail planes.

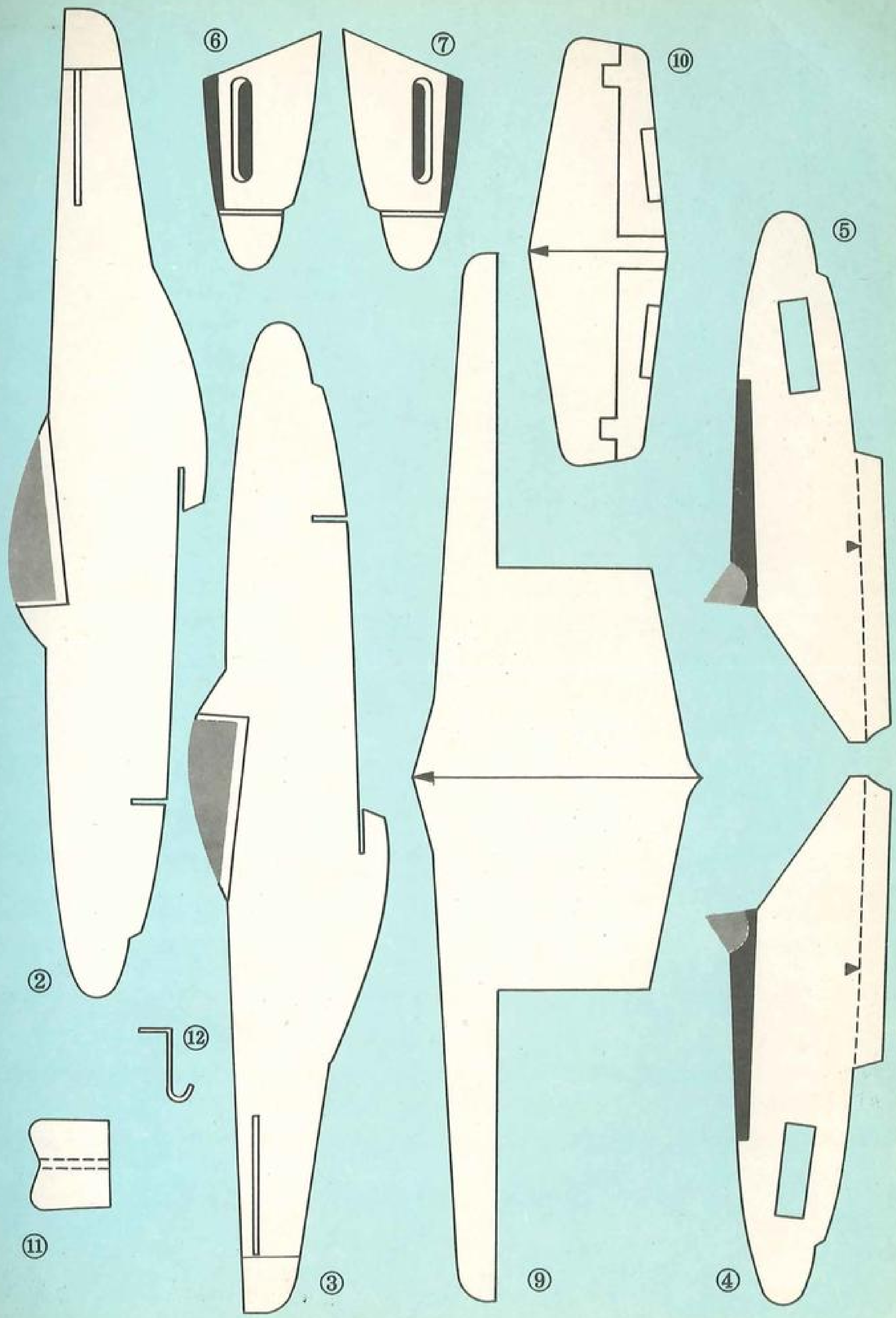
Glue reinforcement ⑨ to main wings ⑧. Insert the horizontal tail plane, and glue the completed wings to the fuselage.




Add the lead foil weight in the nose till the center of gravity falls where it should. Cover the weight compartment with covers ⑥ and ⑦.

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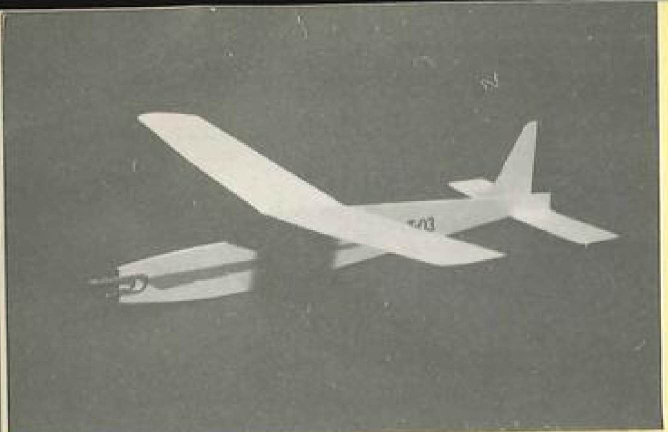
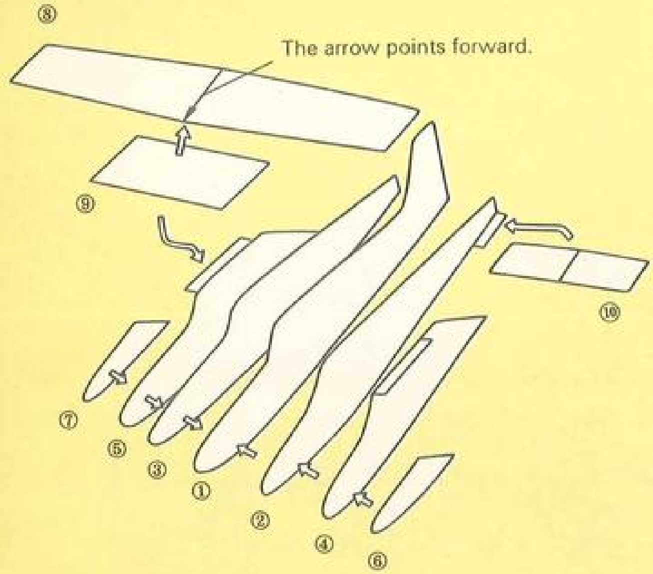


# High-wing Trainer

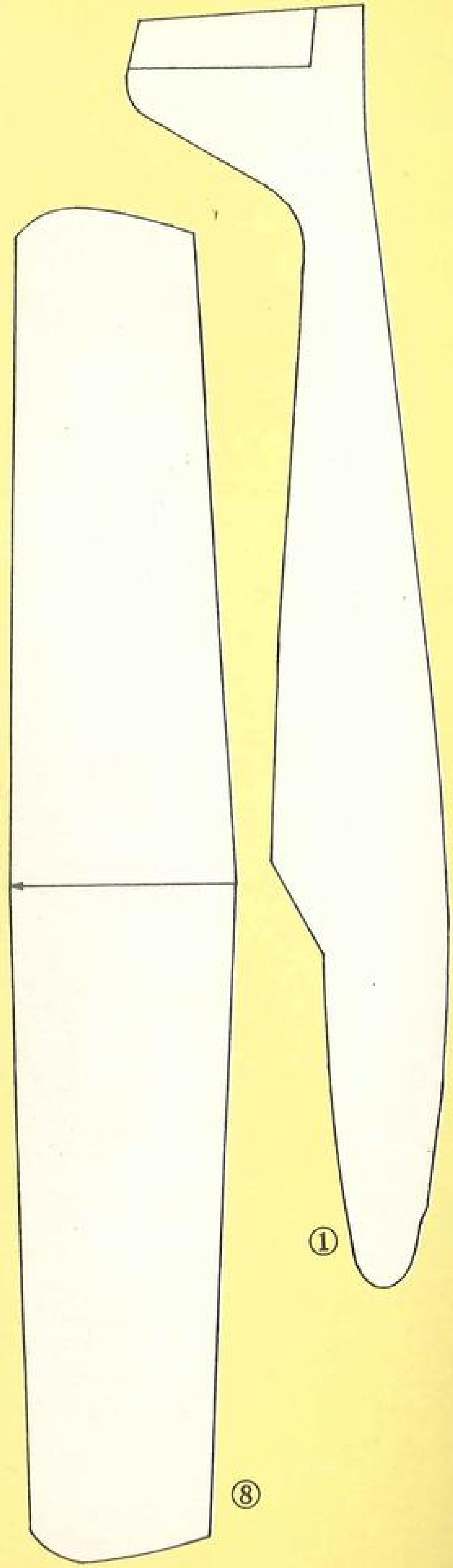
## ASSEMBLY

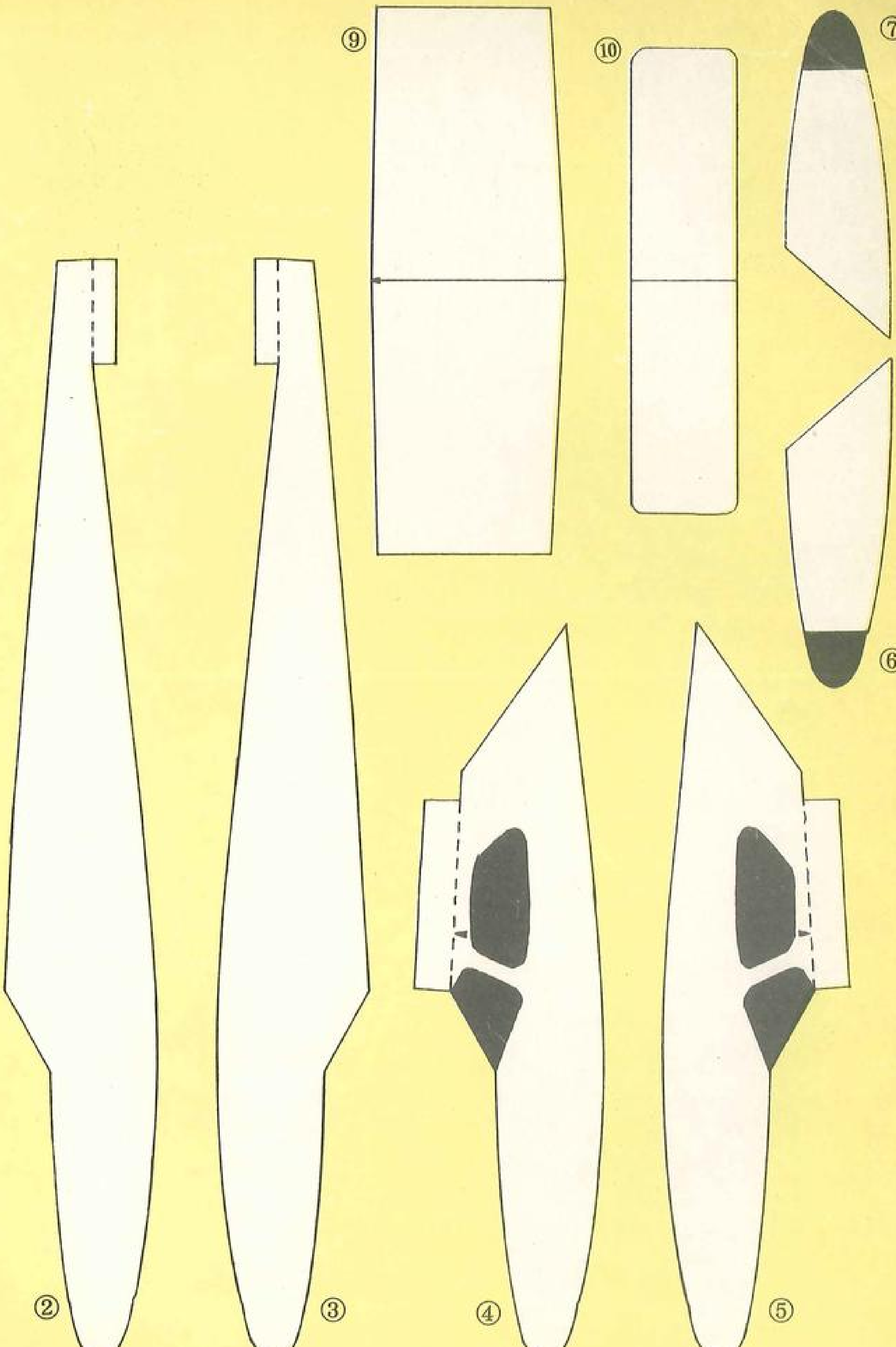
Glue ⑨ to the underside of the main wings.




## ADJUSTMENTS

Wait till the glue is thoroughly dry.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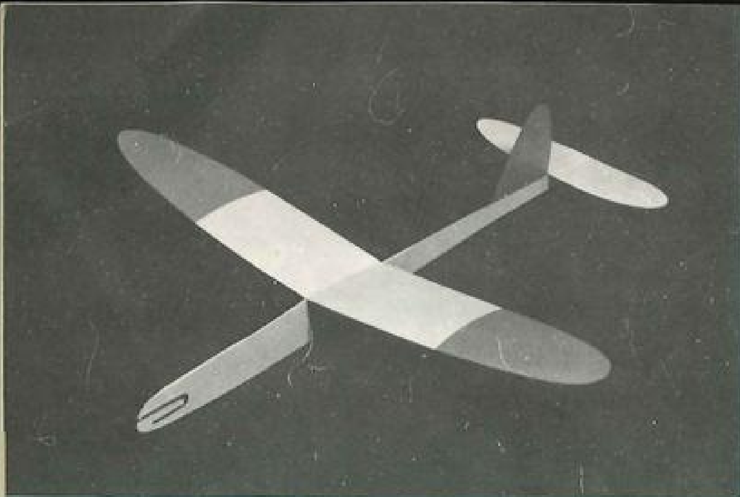
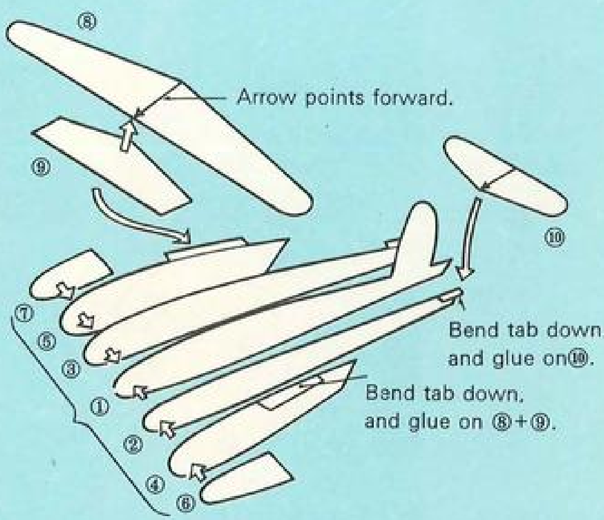
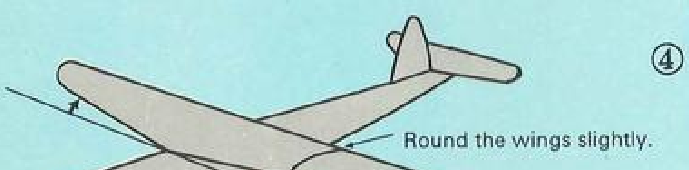


# Racer

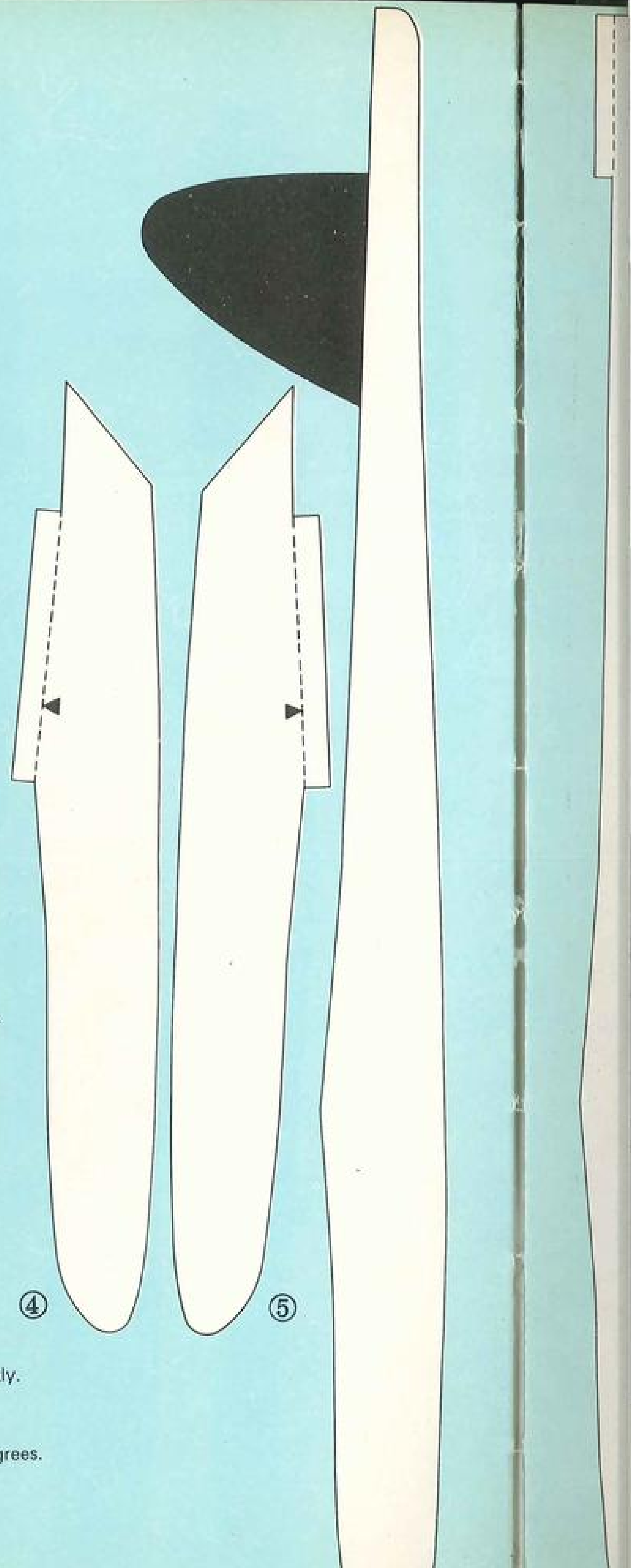
## ASSEMBLY

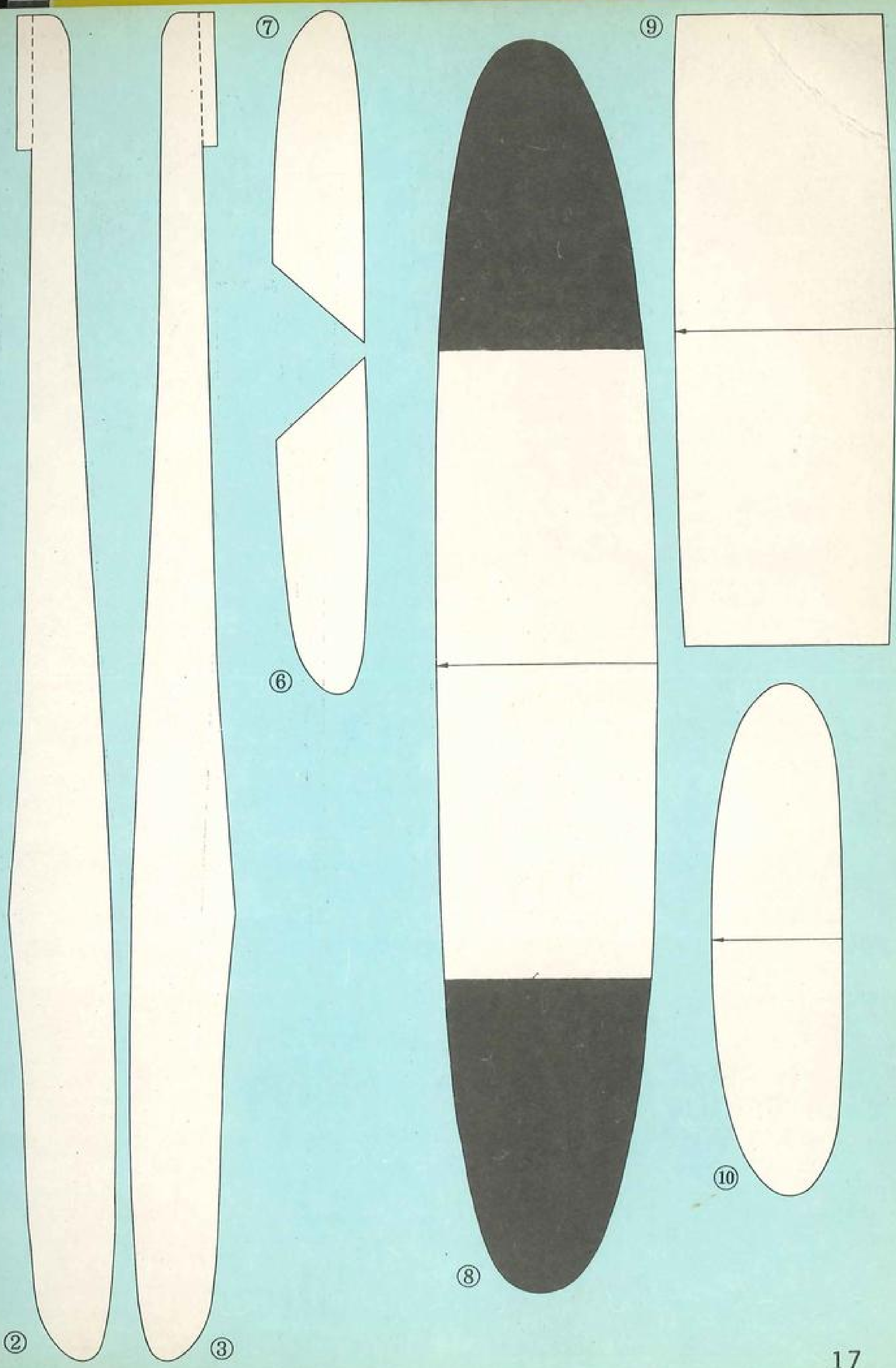



## ADJUSTMENTS




Add a few paper clips to the nose to bring the center of gravity to the place marked ▲.

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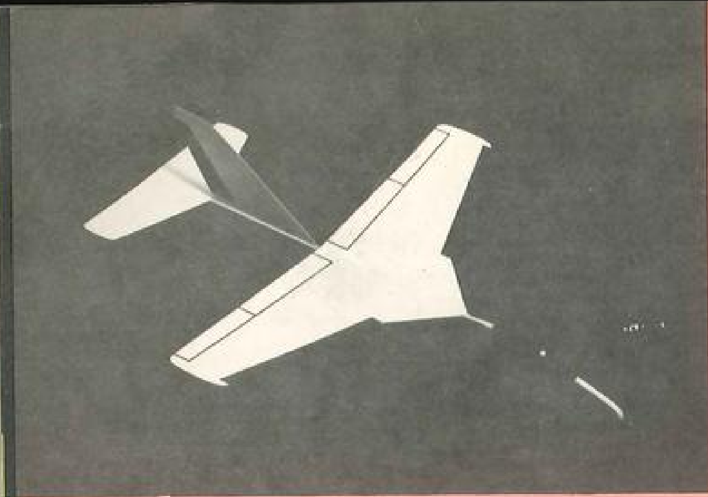
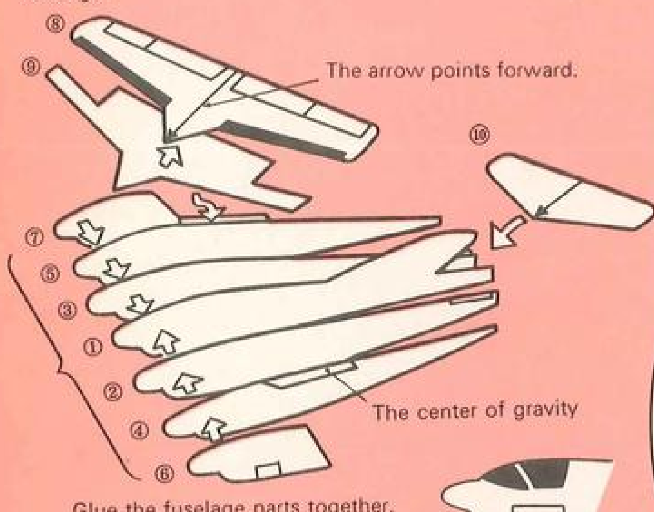


# LTV A7—Corsair II

This version of the Corsair II differs somewhat in configuration from the real plane. The sweep back in the wings is less so that the plane will fly better. This is an easy to make, easy to hold, and easy to fly paper version.

## ASSEMBLY

Glue reinforcement ⑨ to the underside of main wings ⑧; next add the completed wings to the fuselage.



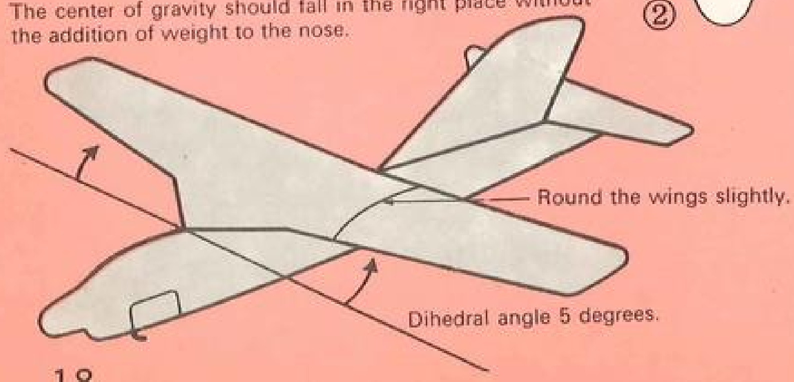

Glue the fuselage parts together.

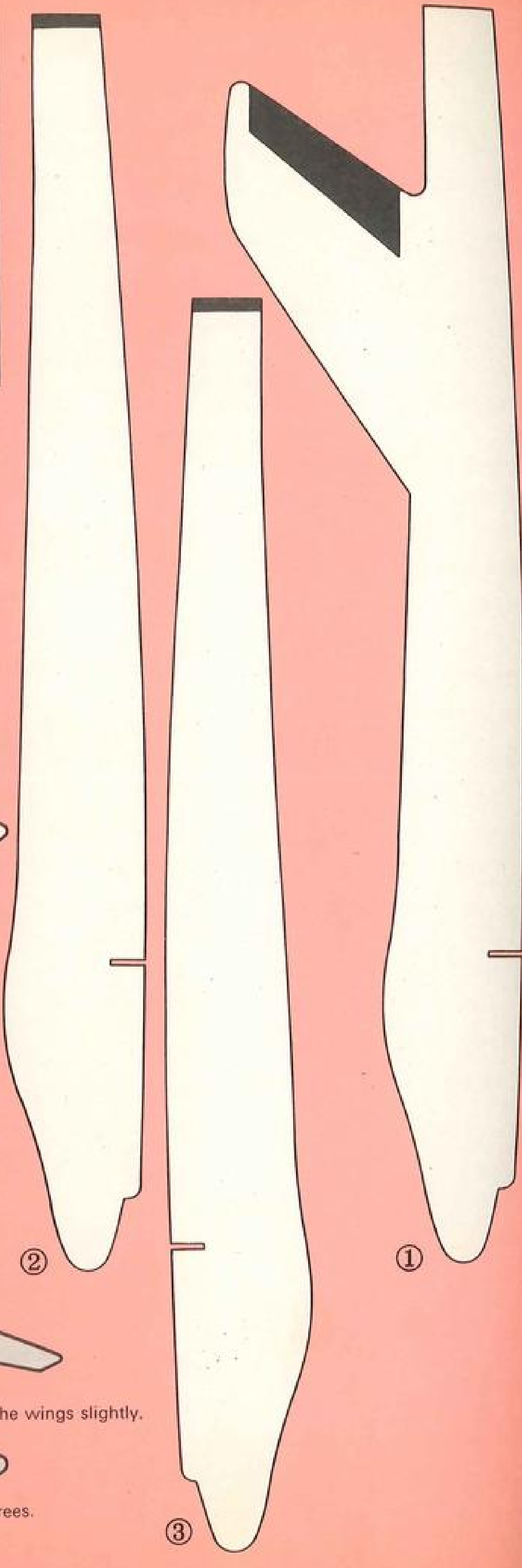

## ADJUSTMENTS

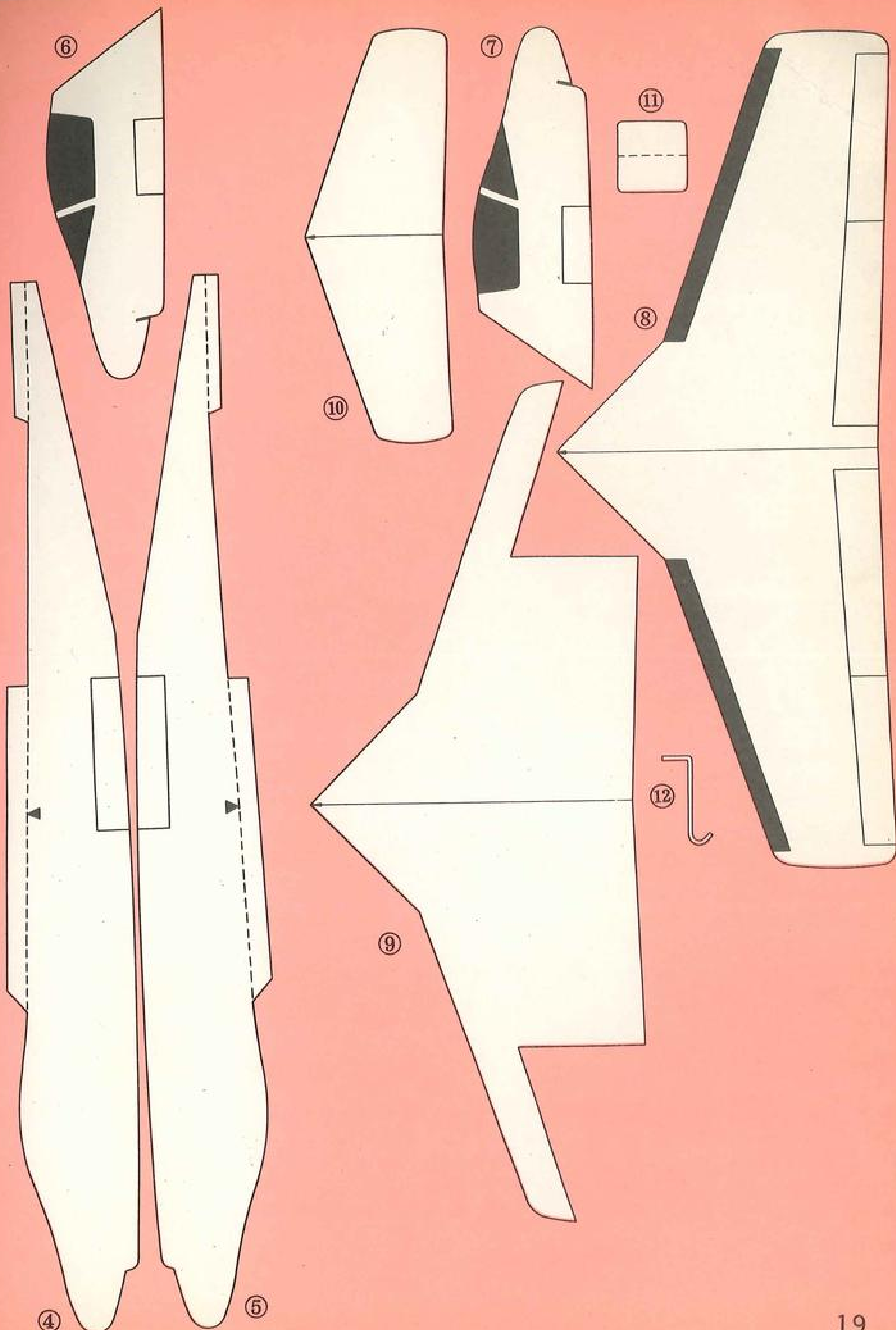
Wait till the glue is thoroughly dry.

Looking at the craft from the front; correct any warp in the wings and fuselage.

The center of gravity should fall in the right place without the addition of weight to the nose.

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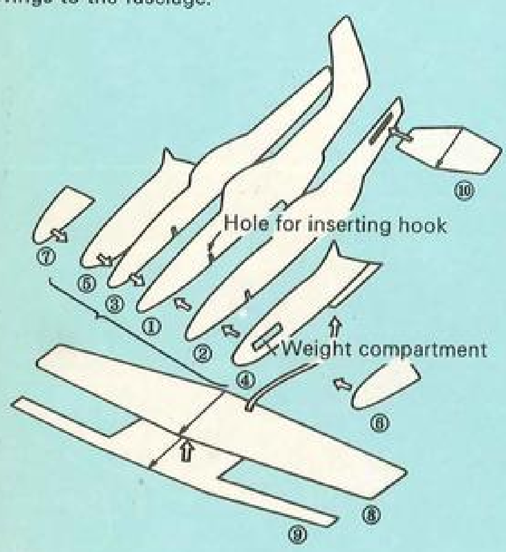
# North-American P-51 —Mustang

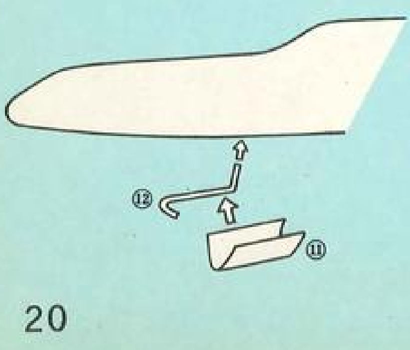
## ASSEMBLY

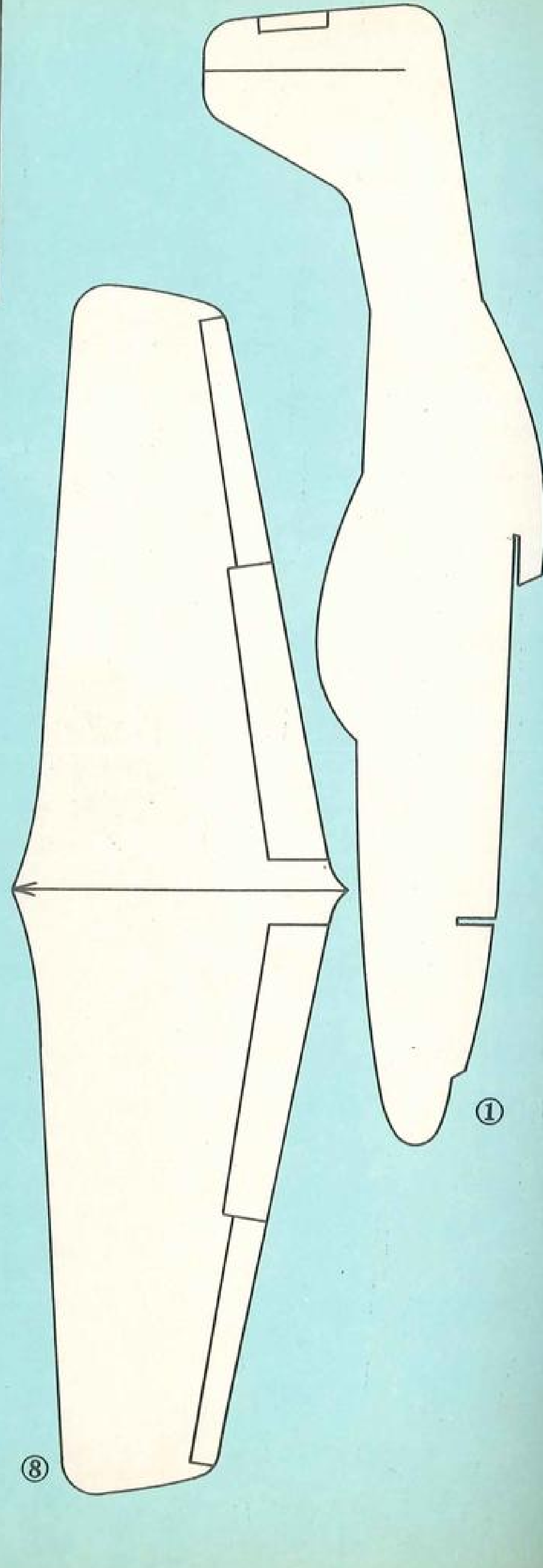
Glue parts ① through ⑤ together; let them dry. Carefully cut the compartment for the lead foil weight in the nose and the slit for the horizontal tail planes.

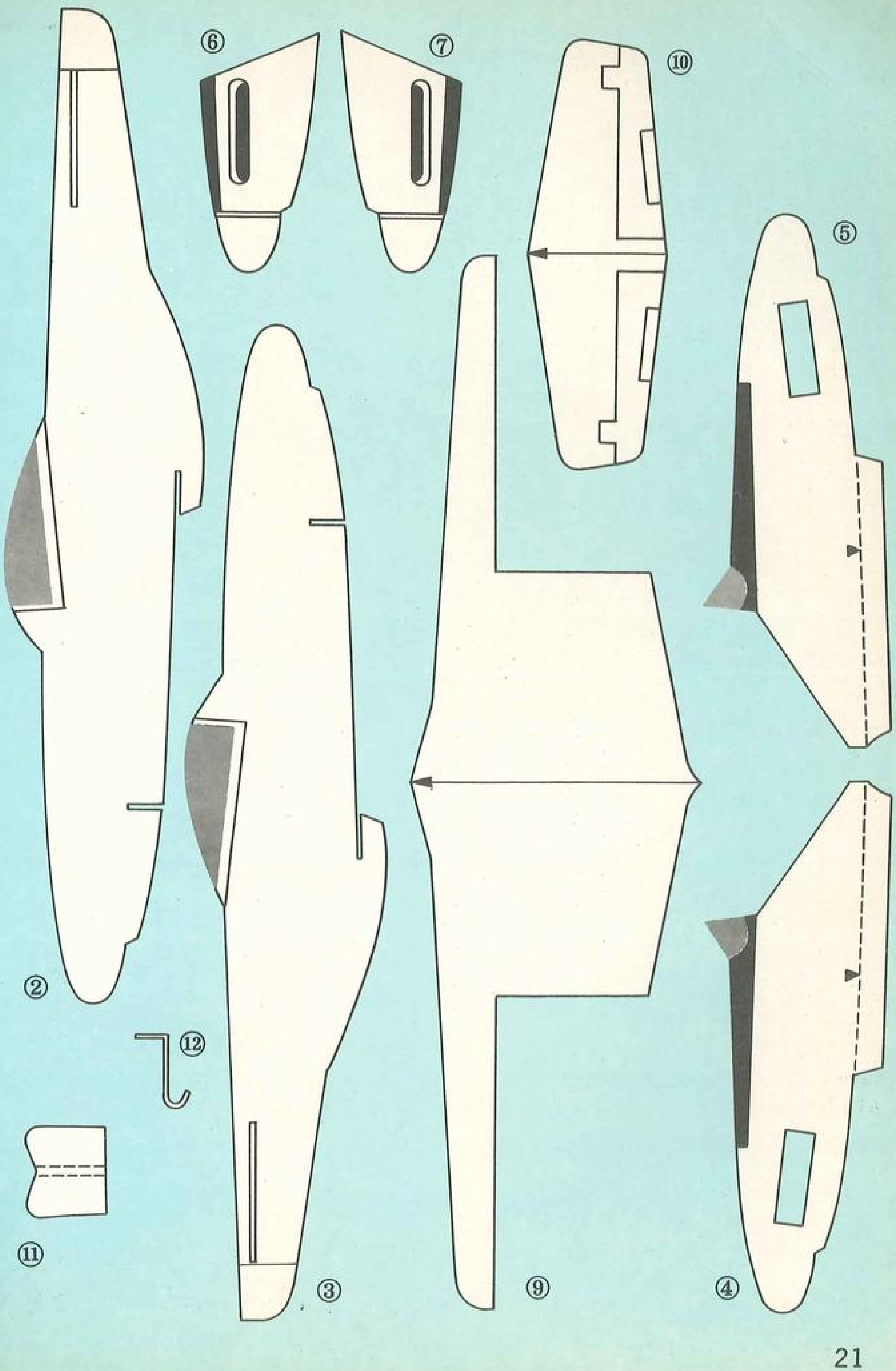
Glue reinforcement ⑨ to main wings ⑧. Insert the horizontal tail plane, and glue the completed wings to the fuselage.




Add the lead foil weight in the nose till the center of gravity falls where it should. Cover the weight compartment with covers ⑥ and ⑦.

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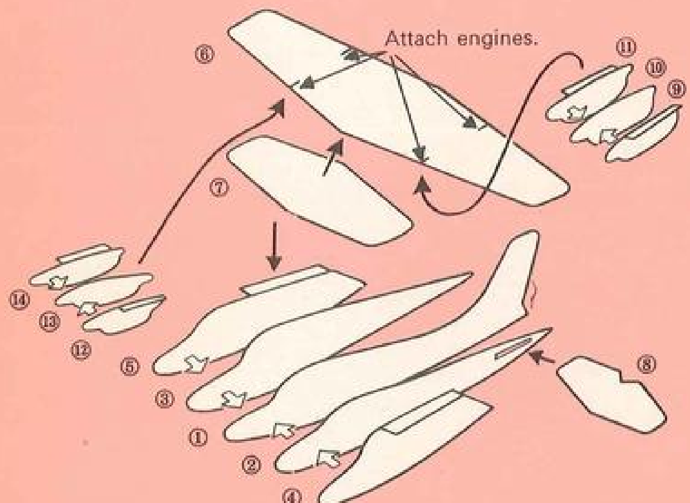
# Mitsubishi MU-2B

## ASSEMBLY

Glue reinforcement ⑦ to the underside of main wings ⑥. Next, using the tabs provided, glue the completed wings to the fuselage.

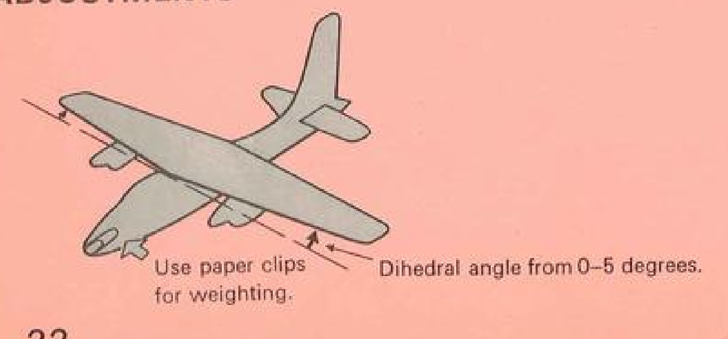
Carefully attach the engines to the main wings after you have glued the engine parts together and let them dry.

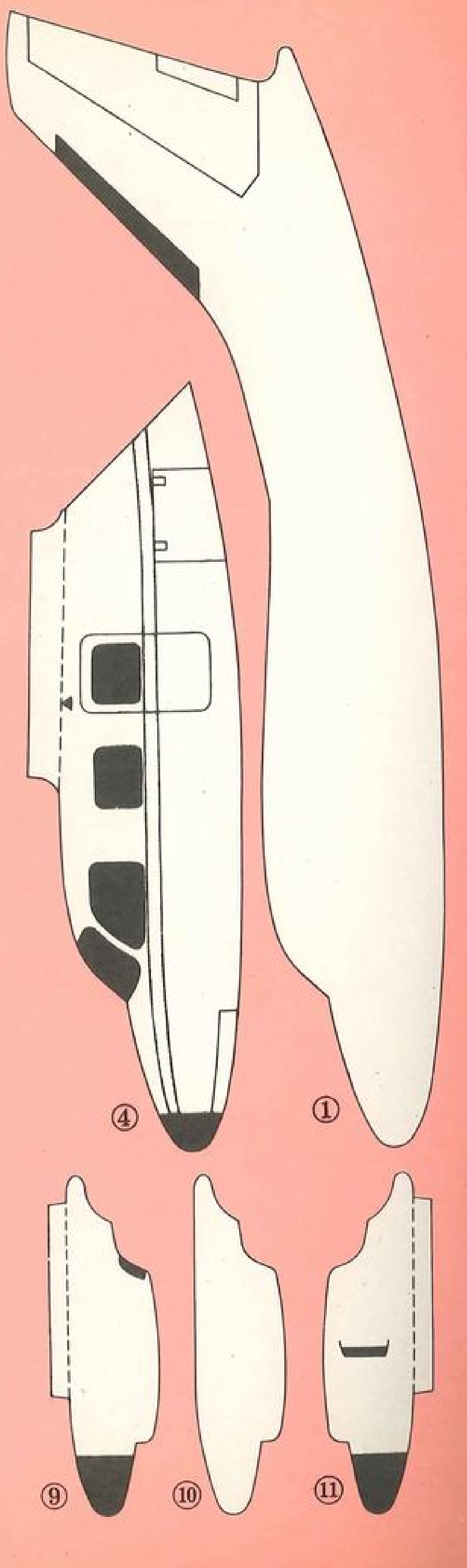


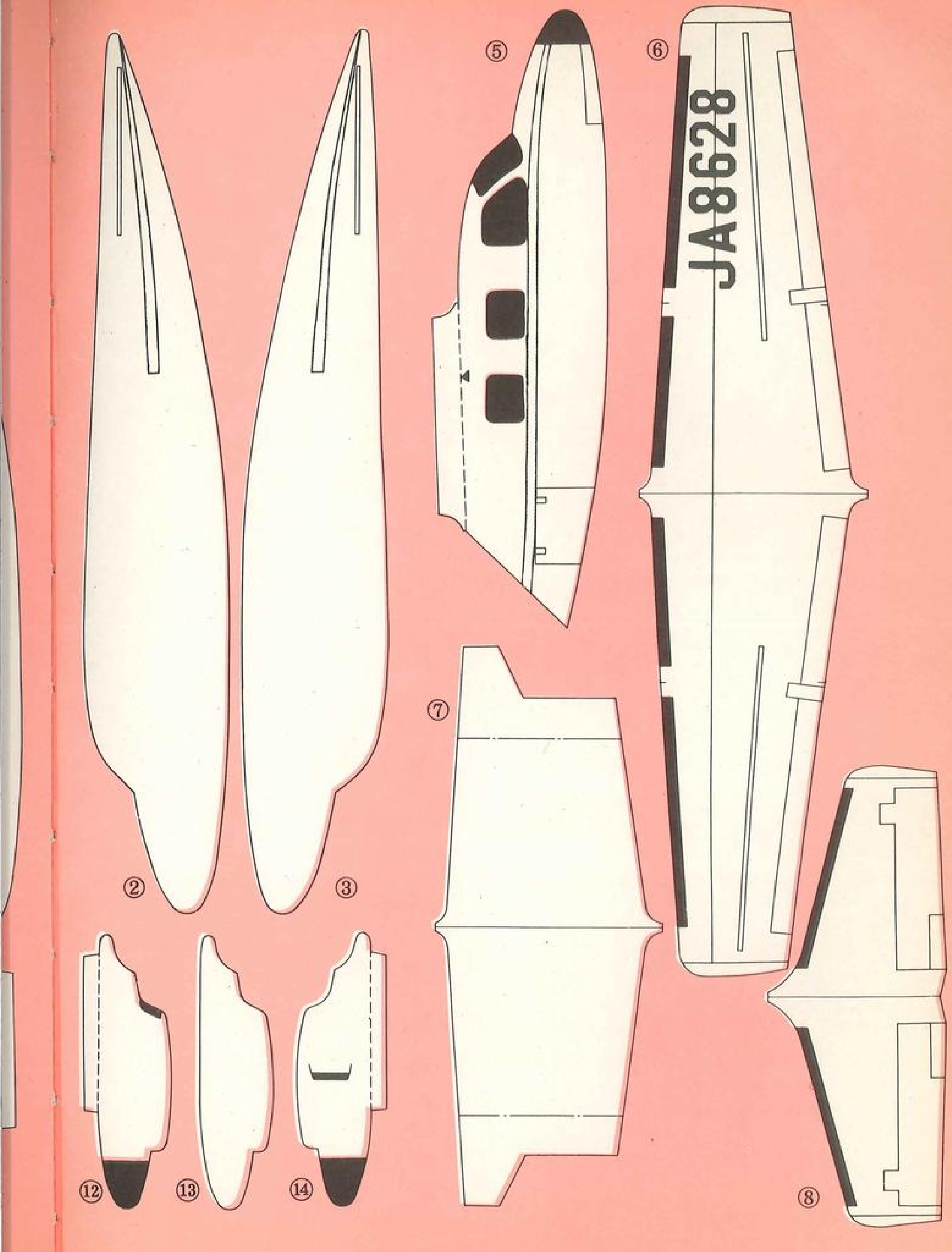

Glue the fuselage parts together, and let them dry. Cut the slit for the horizontal tail planes. Insert them.

Use the marks provided on the wings to make sure you glue the engines on straight and perfectly parallel. If you do not, the plane will not fly straight.

## ADJUSTMENTS

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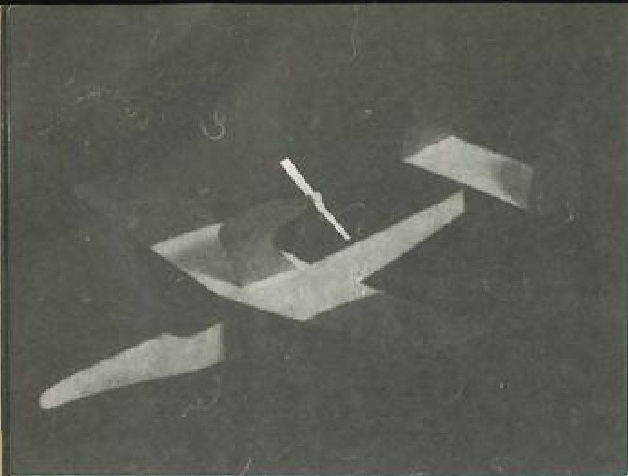
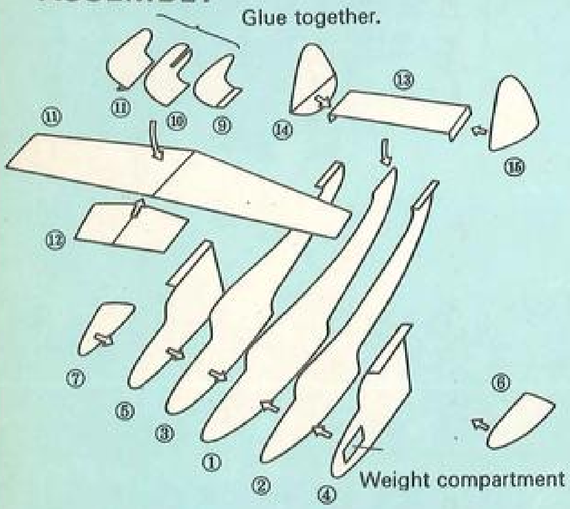


# Flying Boat

## ASSEMBLY




Glue ① through ⑤ together; when they are dry, cut the hole for the weight. If you use paper clips on the nose for weight, omit the weight compartment.

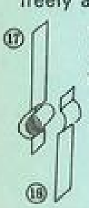
Glue the reinforcement ⑫ to the underside of the main wings ⑪.

Glue the engine parts together then the tail parts.

Add weight to bring the center of gravity to the spot marked ▲. Glue down flaps over the weight compartment.

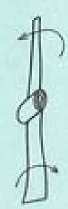
Attach engine, wings, and tail to the fuselage.

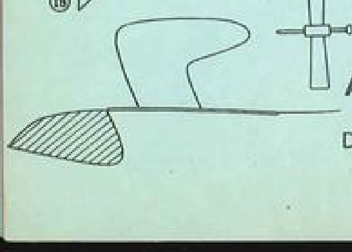
To make the propeller hub, wrap paper strip ⑯ around a straight pin. The paper should revolve freely around the pin.


Glue the blades to the hub as the chart shows. Twist the blades to the proper shape.

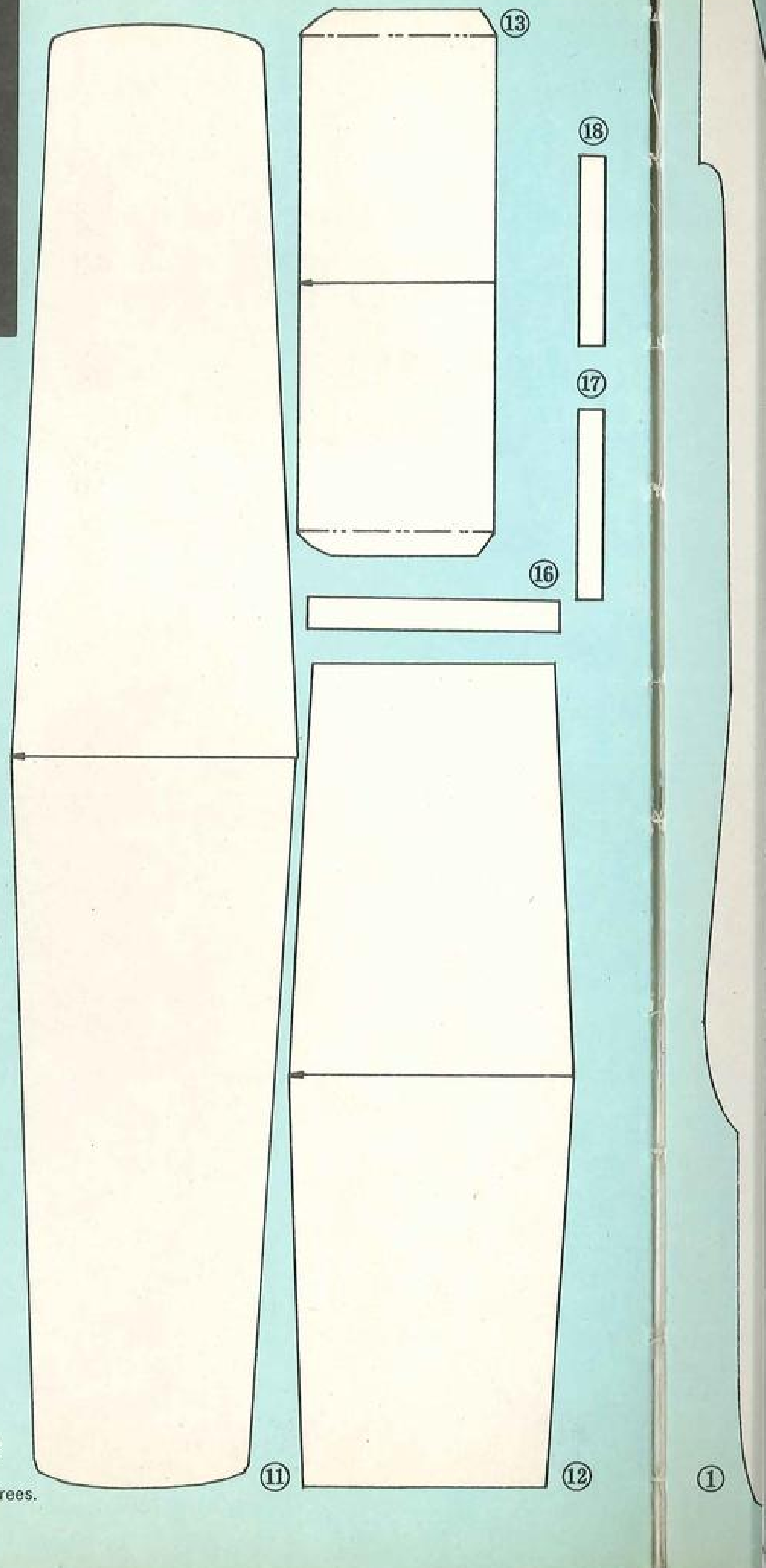
Insert the straight pin into the engine's rear end. Balance it properly.

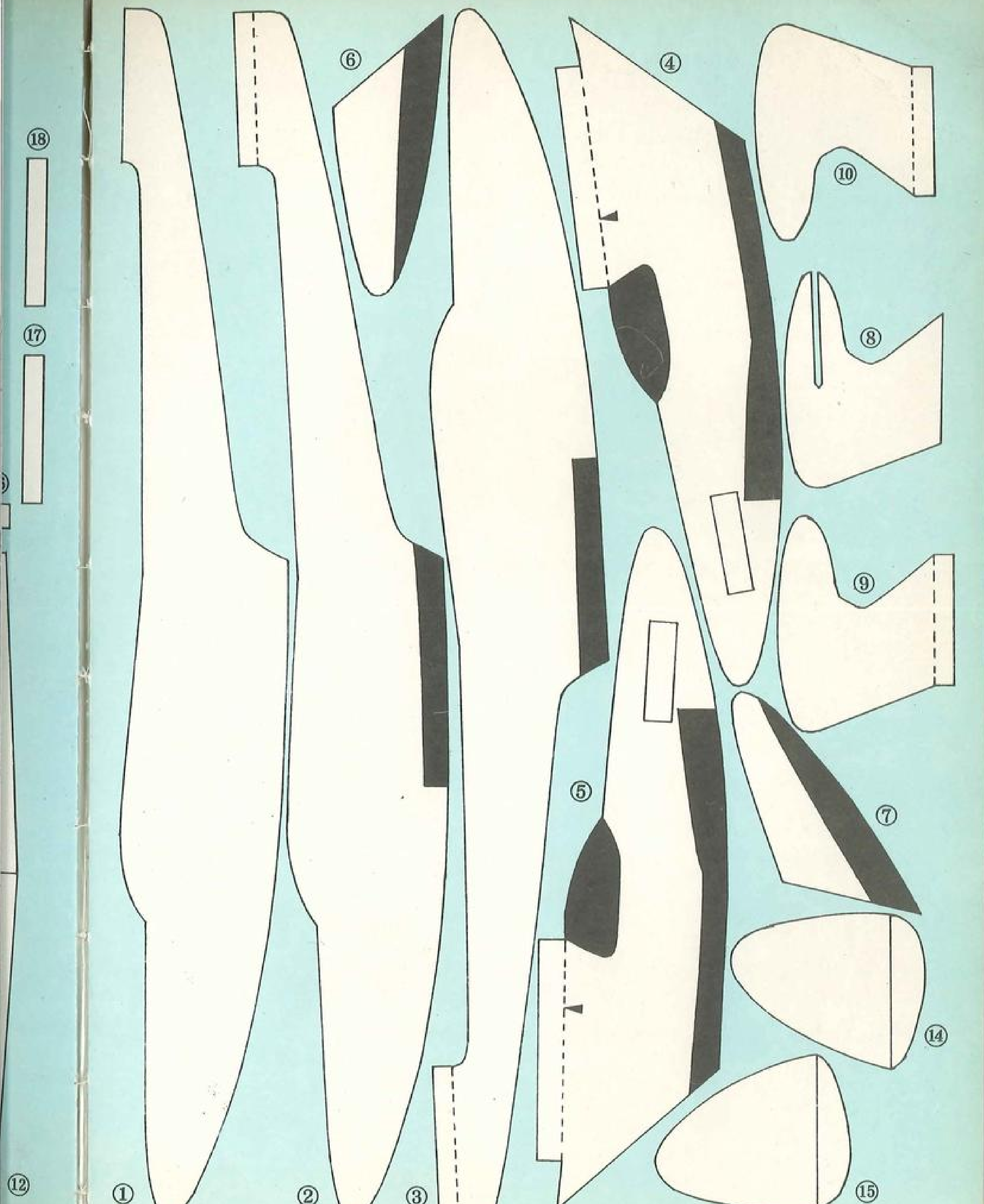




## ADJUSTMENTS

Dihedral angle 5–10 degrees.

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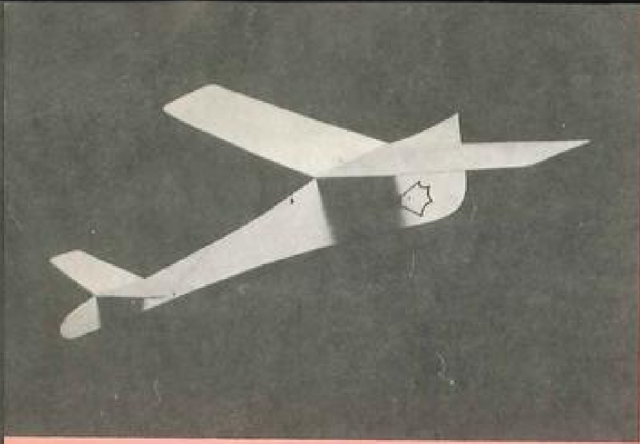
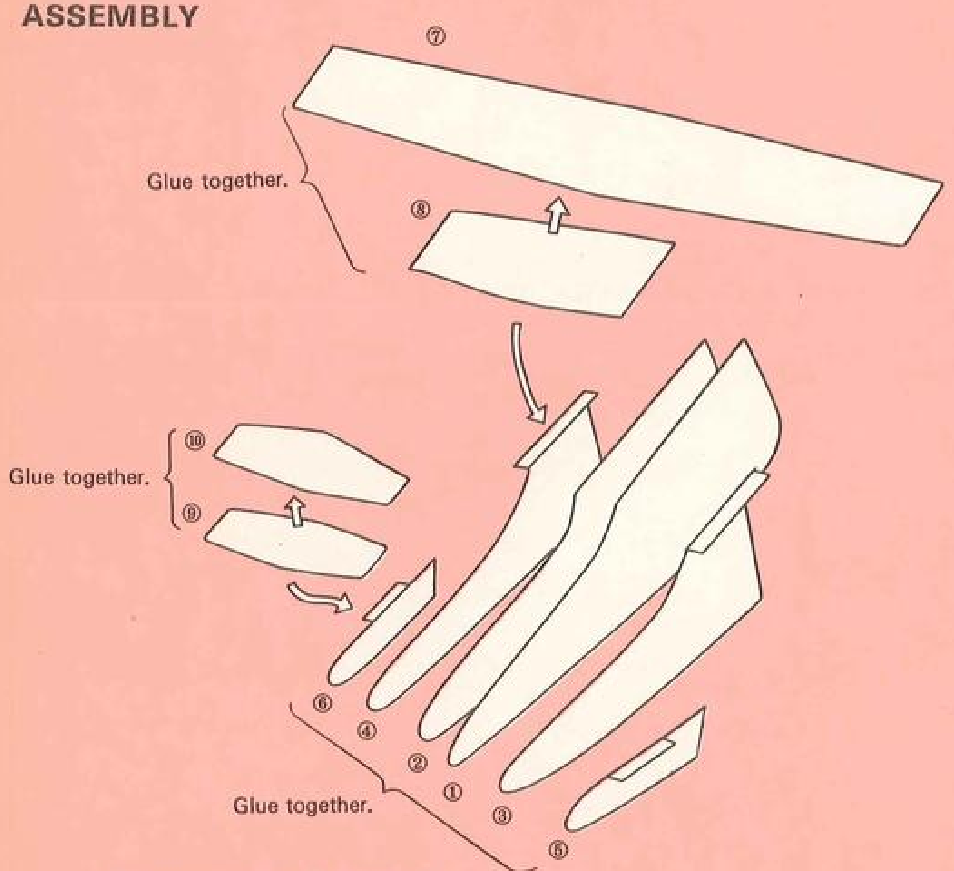


# Canard Craft

## ASSEMBLY



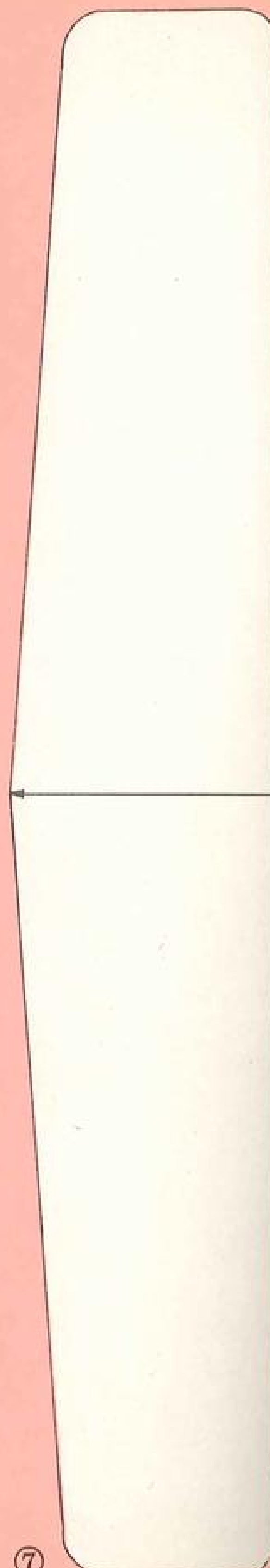

Glue together parts ① through ⑥

When the two wing sets have dried, glue them to the tabs on the fuselage.

## ADJUSTMENTS

Dihedral angles: main wings 5 to 10 degree, front wings 10 to 20 degree.

The center of gravity should fall in the correct place without special weighting.



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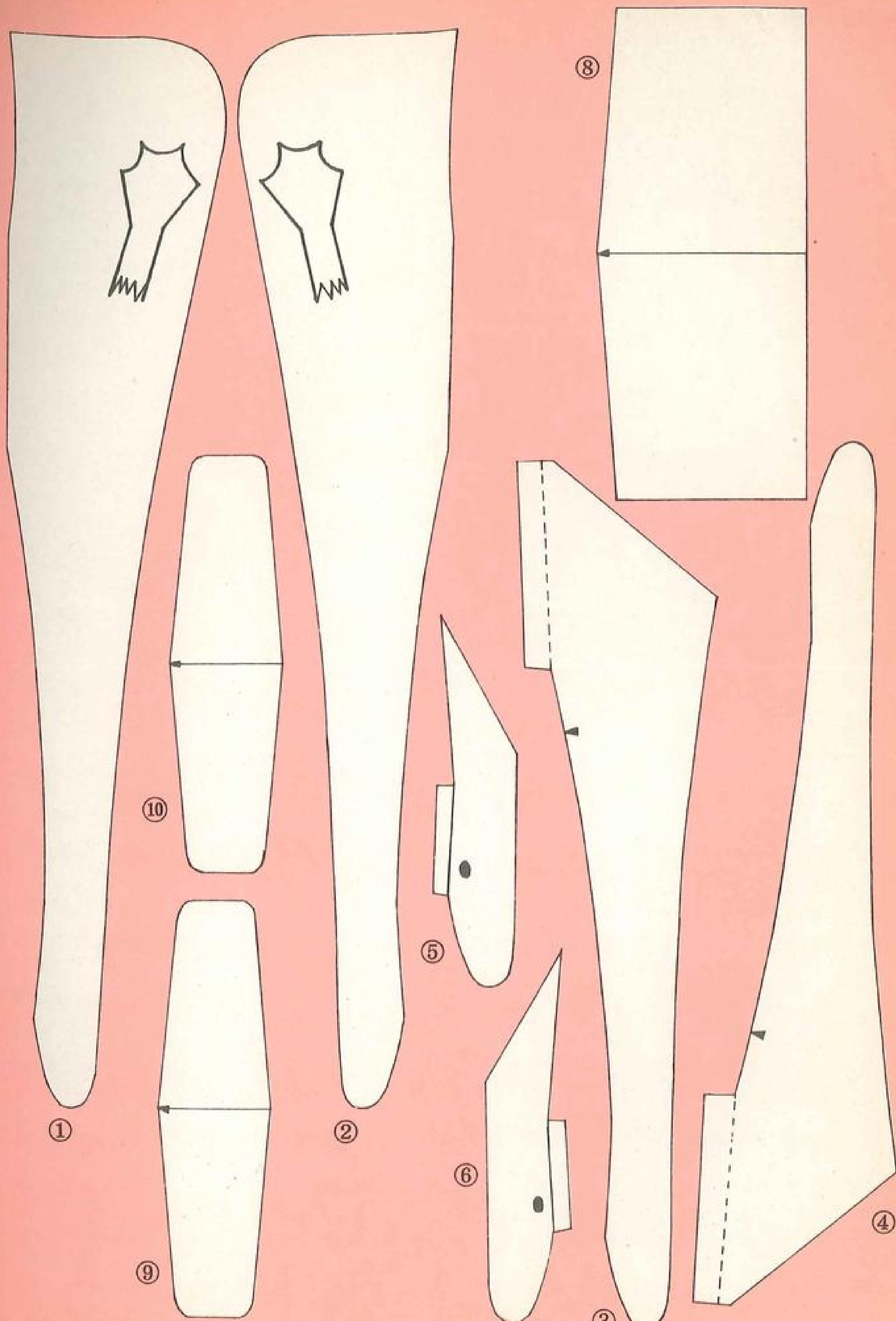
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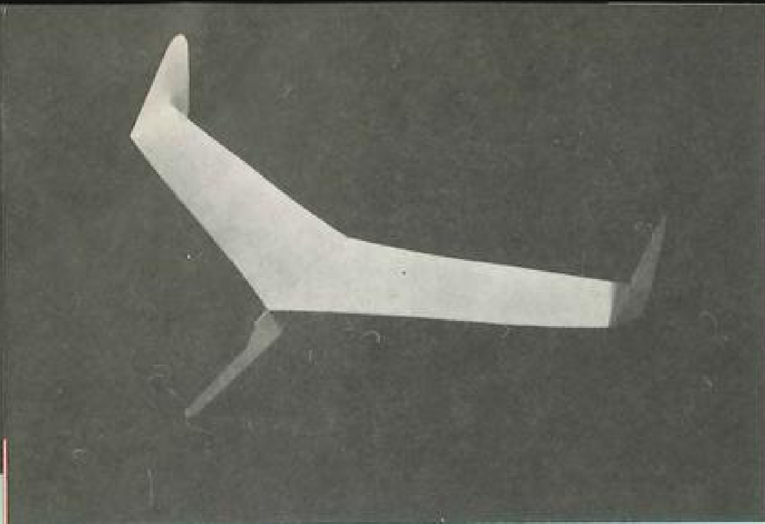
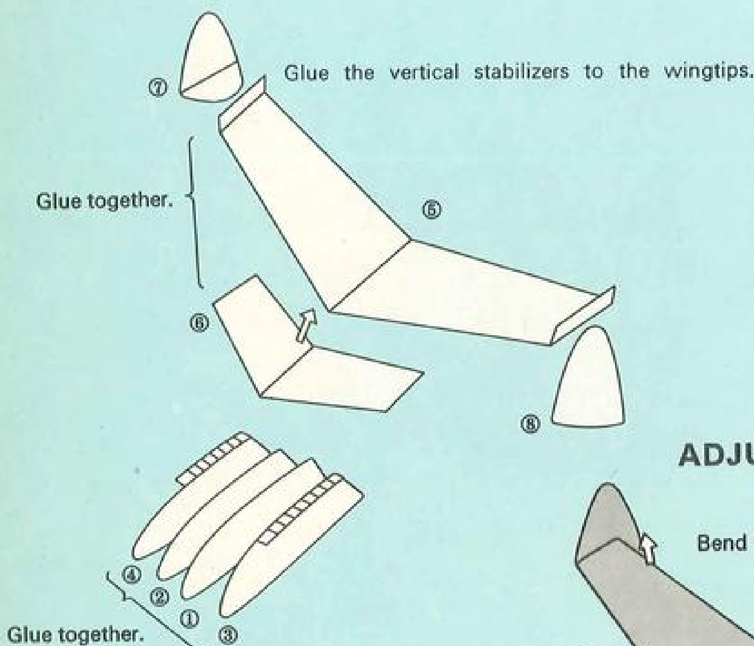


# Tailless Craft

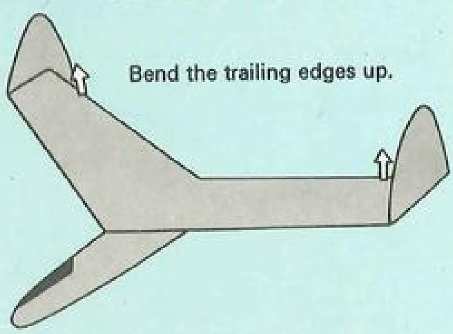
Naturally, tailless craft lack the horizontal tail planes necessary to preserve longitudinal stability. We must use the trailing edges of the main wingtips for this purpose.

## ASSEMBLY

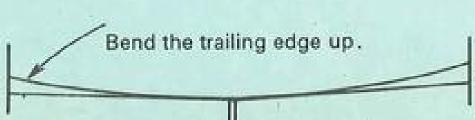


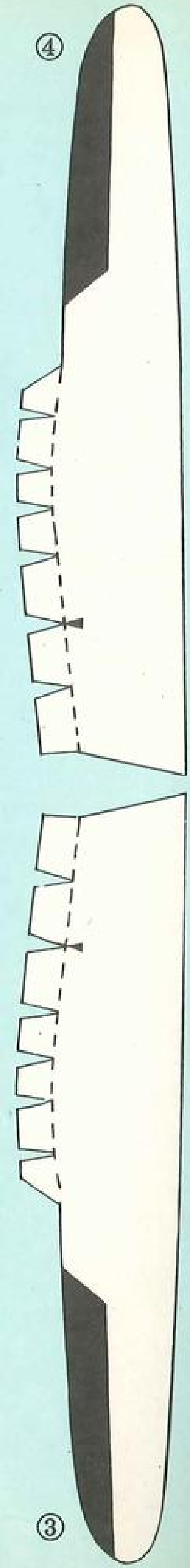

When the wings are thoroughly dry, use your fingers to curve them slightly. Glue them to the fuselage.
The center of gravity should fall in the correct place without special weighting.

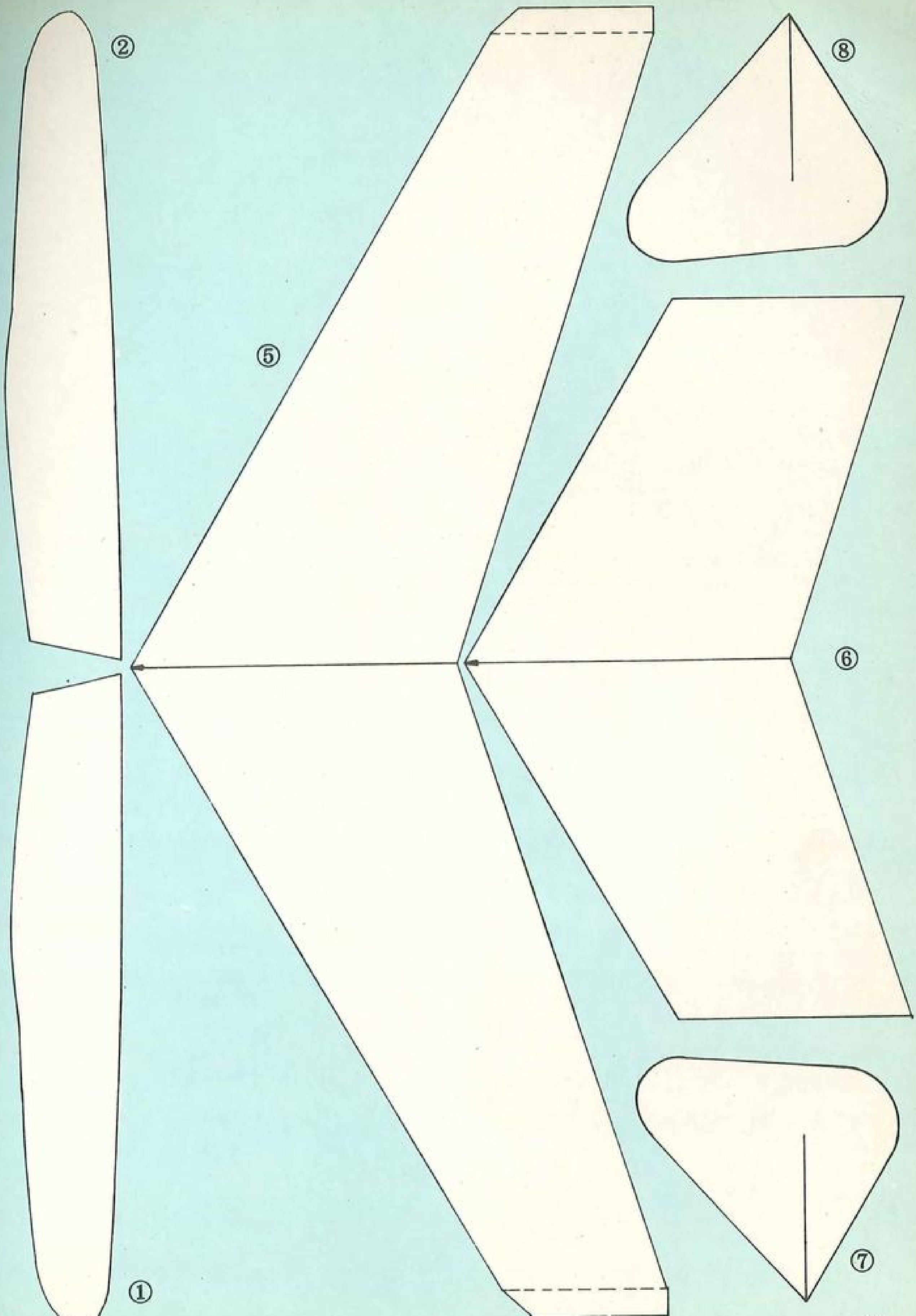
## ADJUSTMENTS




Look at the craft from the front, and bend the wings into the shape shown below. Test fly the craft. If it tends to dive, increase the upward bend of the trailing edge. If it tends to stall, decrease it.

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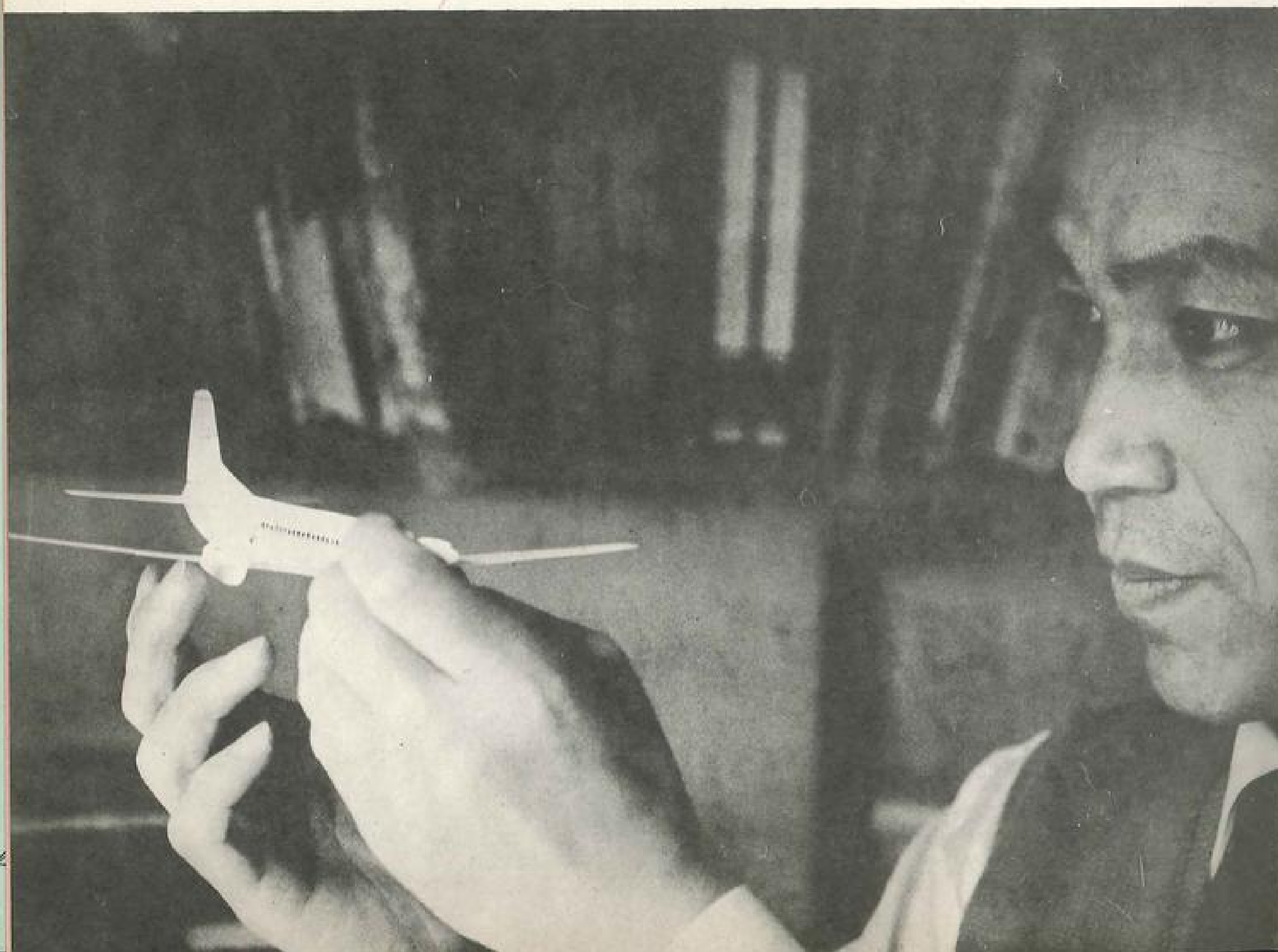
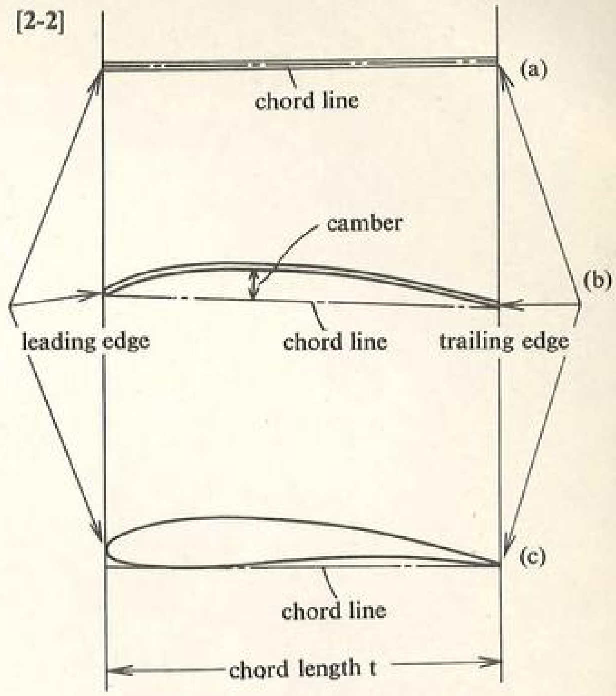
# Principles of Aviation



I give the names of the main parts of the airplane in fig. 2–1. The ailerons, elevators, and rudder serve largely in manipulating the craft. In paper airplanes, we usually do not make special provisions for these parts but make the craft fly as we wish by suitably bending the main wings and the horizontal and vertical tail planes.

The cross section of the main wing, called the airfoil, comes in a number of types as you see in fig. 2–2. The base line of the airfoil is called the chord line. In an arched wing, like b, the chord line is the line that connects the leading edge with the trailing edge. In an airfoil like c, however, we find the chord line assuming a different relationship to the cross section. The length the airfoil projects on the chord line is called the chord length.

[2-2]

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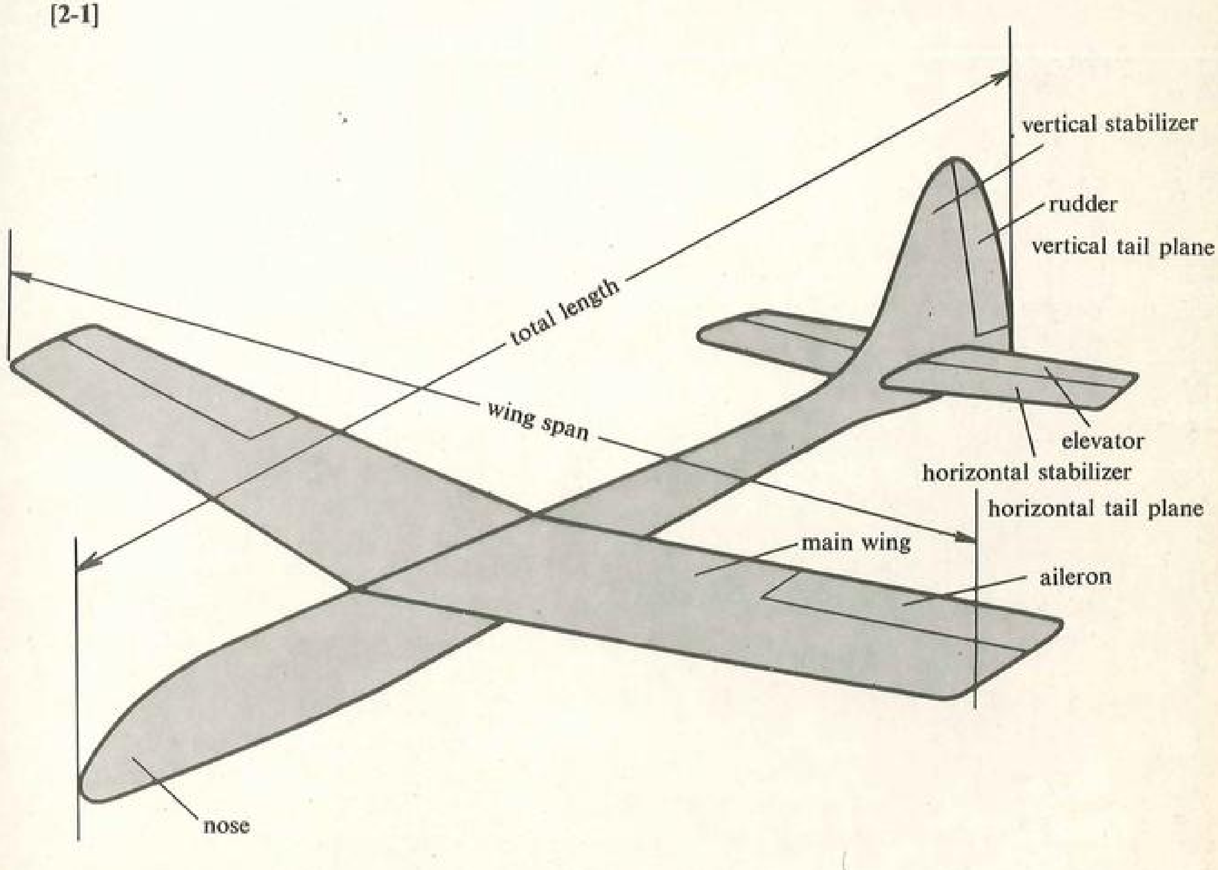
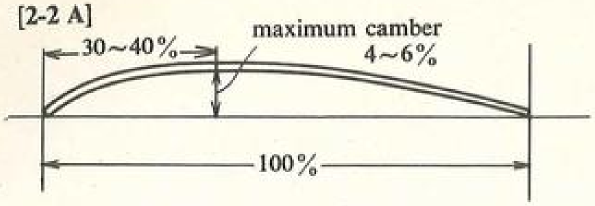


[2-2 A]

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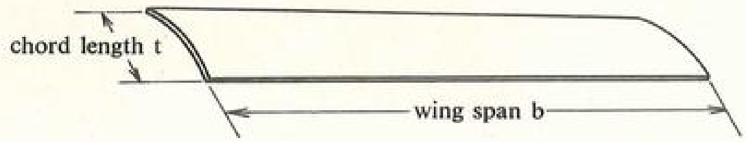


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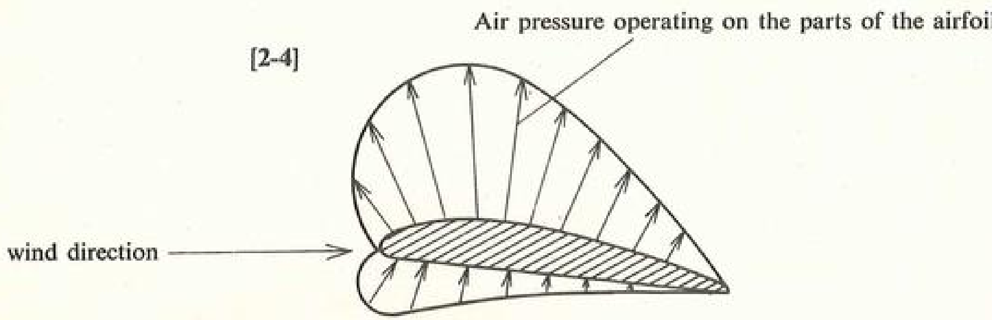



At a point about 30–40 percent back from the leading edge we have a maximum height called maximum camber. (See the bow-shaped wing in fig. 2–2A.) Optimum camber is said to be about 4–6 percent of the chord length.

The aspect ratio, the ratio between the wing span and the chord length, in the case of a rectangular wing (fig. 2–3), can be worked out by means of the following formula:

$$\text{aspect ratio } R = \frac{\text{wing span}}{\text{chord length}} = \frac{b}{t}$$

With wings of other than rectangular form, we use the mean chord $t_m$. In this case, the aspect ratio is arrived at by means of the following formula:

$$R = \frac{b}{t_m}$$

Since the mean chord length ($t_m$) is the result of dividing the wing area, S ($= b \times t_m$) by the wing span, b, the formula for the aspect ratio in this case becomes

$$R = \frac{b^2}{S}$$

I will take time now to explain a few more words you will need.

Wing load: The value obtained by dividing the total weight of the airplane W by the area of the wing S.

Angle of attachment: The angle at which the chord of the main wing or that of the horizontal wing plane joins the fuselage.

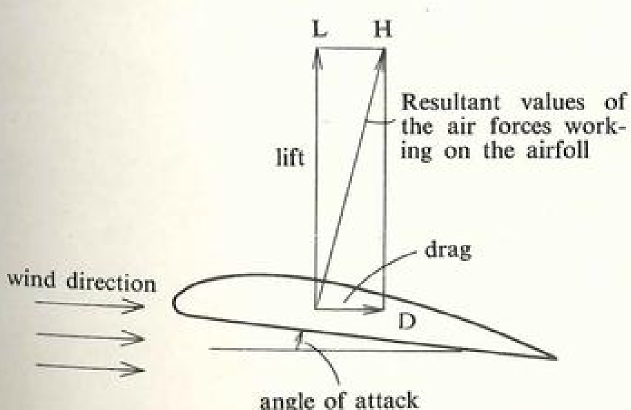
Wing attack angle: The angle at which the wing plane must advance. When the base line of the fuselage and the craft's direction of advance are the same, the angle of attack and the angle of attachment are the same. The base line is established for a number of reasons, including maneuverability, and does not always coincide with the direction of advance. For this reason it is essential to clarify the point.

## Lift on the Main Wings

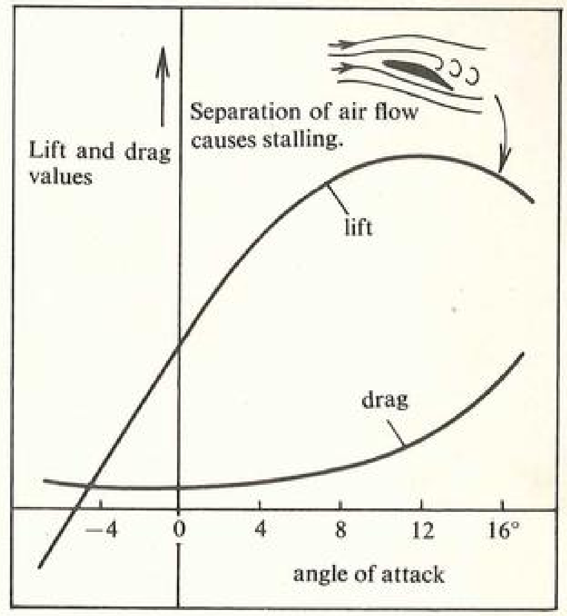
The wings are the most important factor in keeping the plane aloft. As you see in fig. 2–4, when the plane advances, the wind it encounters causes one set of forces acting in an upward sucking fashion and another set that pushes upward from below. Considered as one, the distributed forces may be represented by H, as you seen in fig. 2–5. We call the place on which this compound force acts the lift center. We divide force H into the force D, that acts in the direction of the wind the plane encounters, and the force L, that acts at right angles to force D. Force D, acting against the wing's forward advance is called drag. L is called lift. L/D the lift/drag ratio is the criterion by which we determine whether a wing is good or bad. The bigger that ratio, the greater the lift and, consequently, the better the wing.

As fig. 2–6 shows, we alter the lift and drag by changing the angle of attack. Fig. 2–7 shows changes in the lift/drag ratio caused by changes in the angle of attack. For ordinary wings, an angle of attack of about four degrees is best. These charts are for wings only. When we add the resistance caused by the fuselage, we generally have to increase the angle of attack to from five to six degrees.

[2-5]

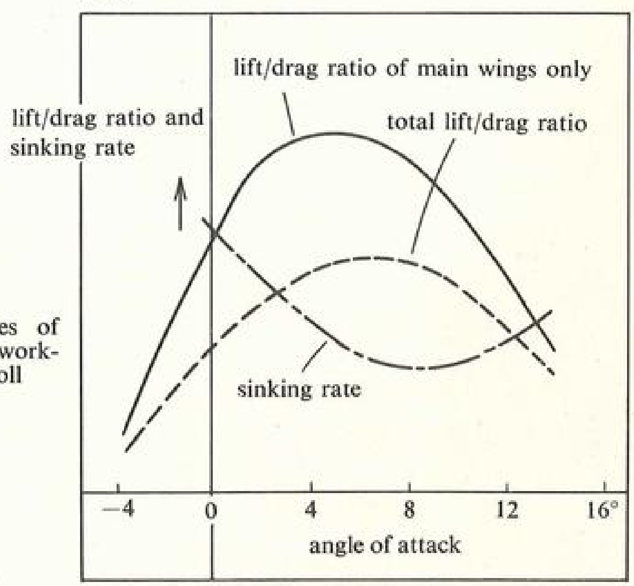



[2-6]




Examples of changes in lift and drag depending on the angle of attack.

[2-7]




Changes in lift/drag ratio and sinking speed depending on changes in the angle of attack.

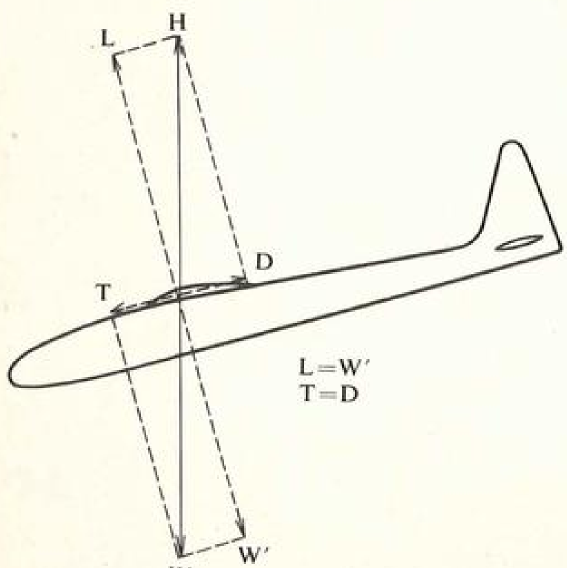
## Drag

Three types of drag act on aircraft.

Pressure drag
Frictional drag
Induced drag

We reduce pressure drag by making the fuselage cross section as small in area as possible and by streamlining. The aspect ratio of the main wing is a determing factor in induced drag. The greater that ratio, the smaller the resistance. In real gliders, to reduce induced drag as much as possible, we use main wings with high aspect ratios. We do the same in designs for long-range aircraft. Since in small, slow-flying paper aircraft the other drags are more important than induced drag, we need not worry about making wings with aspect ratios so large that we sacrifice strength. On the contrary, with paper airplanes, it is much more advantageous to suit this ratio to the demands of the paper's strength and to strive for light, strong wings.

[2-8]




Balance of forces during a glide

## Glider Flight

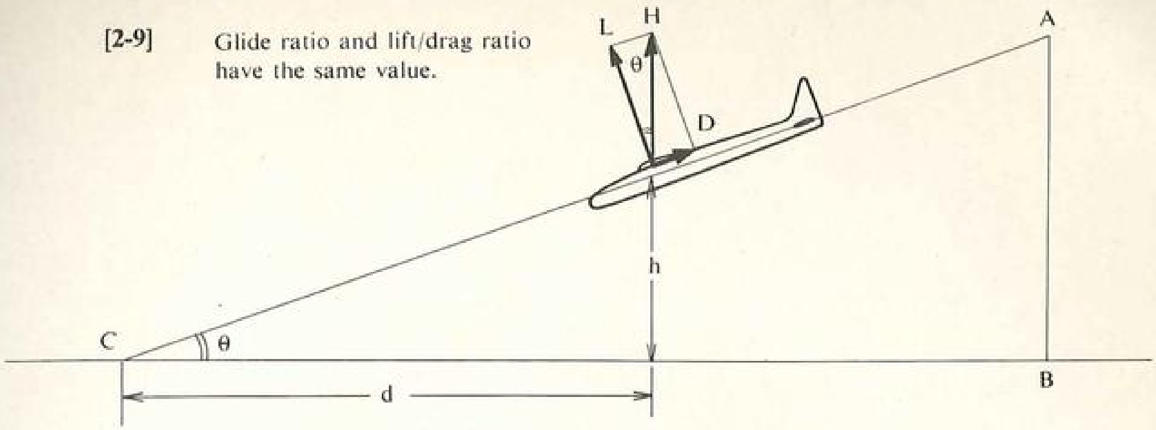
When the plane glides at a steady speed (stationary gliding), the plane's total weight W and the wind pressure H working on the wings maintain balance. As you see in fig. 2–8, part of the plane's weight T pulls the craft forward in balance with the drag D at work on the airframe. The remainder of the weight W′ balances with the lift L on the wings, and maintains a glide at a constant speed. We call the ratio between the altitude of the plane and the distance it will glide its glide ratio, which is equal to the total lift/drag ratio L/D of the entire plane (fig. 2–9). To make the glider go as far as possible at a fixed altitude, it is necessary to make the lift/drag ratio as large as possible. To do this, we have to be careful to design airframes that have as little harmful drag as possible. The airfoils in fig. 2–2 appear in ascending order of worth as far as lift/drag ratio goes, but with small low-speed paper planes, the good and bad properties of the airfoil are not critical enough to warrant our making highly elaborate wing designs. Generally, we will concentrate on airfoil shape b.

To lengthen the duration of flight of an aircraft we must minimize its rate of sinking. The glider in fig. 2–9, in gliding from A to C, sinks the distance AB.

Sinking rate is measured in meters per second. If it is small, a plane will take longer to land than another which, though it began at the same altitude, has a higher sinking rate.

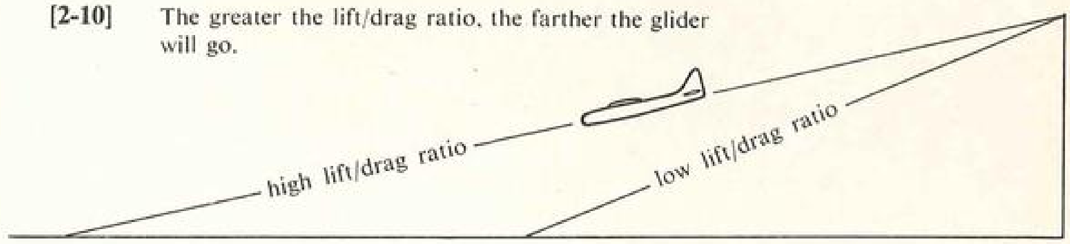
Fig. 2–9 should give you a good idea of how to minimize the sinking rate. You increase the lift/drag ratio and decrease the glide speed. As we have noted, to make the former smaller, it is essential to reduce drag. To decrease the glide speed, the lift must be increased and the wing load decreased. To increase the lift, we must make the angle of attack of the main wing slightly larger than the attack angle that gives a maximum lift/drag ratio. To reduce the wing load, we should increase their areas, but to make them too large is to reduce their strength. Rather than do this, we should aim for a strong, light over-all airframe.

[2-9] Glide ratio and lift/drag ratio have the same value.




$$\text{glide ratio} = \frac{d}{h} = \frac{L}{D}$$

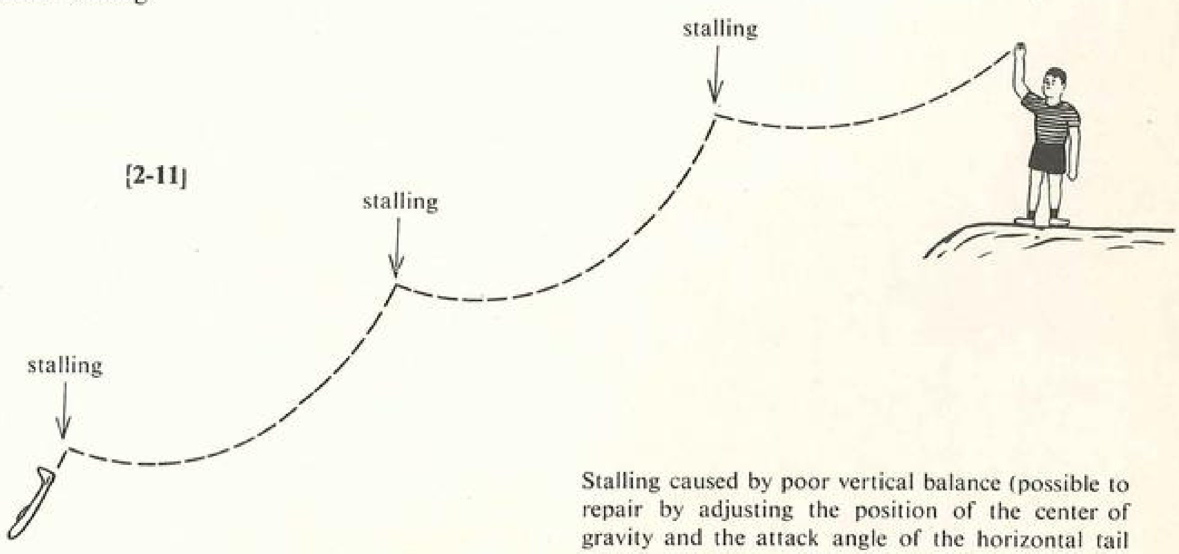
[2-10] The greater the lift/drag ratio, the farther the glider will go.




## Stalling

We have said that the lift gradually increases with increases in the angle of attack, but once that angle reaches more than 12 or 13 degrees, the lift suddenly drops because the flow of air separates above the wing's surface. This phenomenon is called stalling.

[2-11]




Stalling caused by poor vertical balance (possible to repair by adjusting the position of the center of gravity and the attack angle of the horizontal tail planes).

A model airplane that flies like the one in fig. 2–11, cannot return to normal level after a nose-up position because its vertical balance is poor. It, consequently, continues to head up losing speed and increasing the angle of attack until it stalls. It then suddenly lowers its nose and repeats the whole process. Stalling causes extreme losses of altitude. You must correct it in your paper airplanes by adjusting the position of the center of gravity and by correcting the angle of attack of the horizontal tail planes.

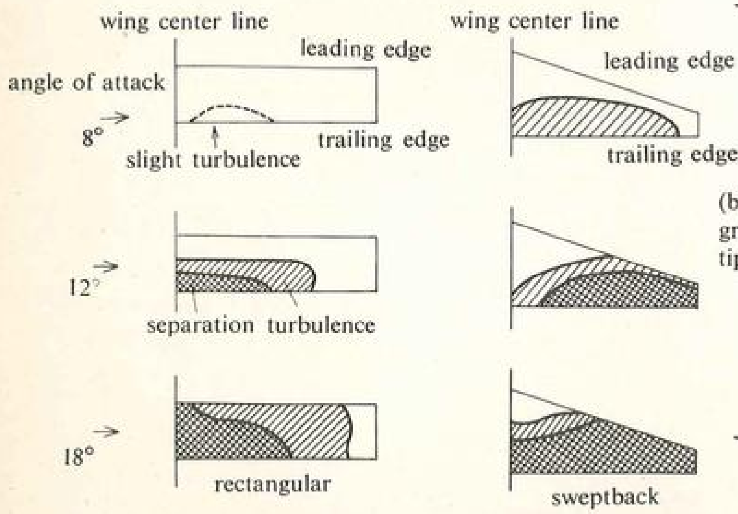
Recent airplanes, designed to fly at the speed of sound, often use sweptback wings to overcome certain unfavorable phenomenon occuring at great speeds. If you attempt to copy these wing in ordinary models, you will find that the wing tips will stall easily. It is best to avoid sweptback wings.

Testing both the rectangular and the sweptback wing for stall, we see (fig. 2–12. *Report & Memorandum No. 1796* of the Royal Aircraft Establishment) that as the angle of attack increases, the rectangular wing begins to stall at from eight to fourteen degrees near the joint between the fuselage and the wing root. The sweptback wing, on the other hand, begins to stall first from the tip. We call this wingtip stall.

Turbulence in the air and slight twistings in the wings result in differences in stall on the right and left wings. As you see in fig. 2–13, when the stall difference is at the root of the wings, the tendency for the plane to roll over is slighter than it is when the stall occurs at the tips. Consequently, when a plane with rectangular wing stalls, it may lose altitude, but it will continue to fly straight. Should a plan with sweptback wings stall, it can roll over or go into a spin. This means that, when we use sweptback wings, we must decrease the main wing's angle of attack and adjust the center of gravity and the angle of attack of the horizontal tail planes to the needs of high-speed flying. We can also reduce wingtip stall by bending the tips to a smaller angle of attack than that at the wing roots (fig. 2–14).

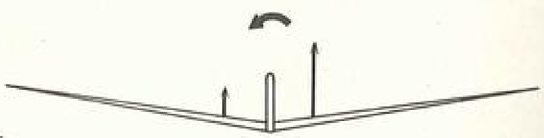
**[2-12]**

Stalling in rectangular wings and in sweptback wings

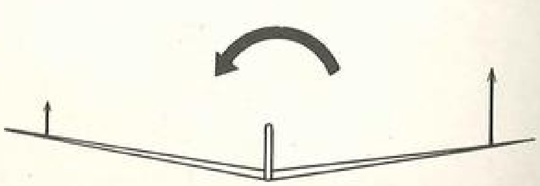



**[2-13]**

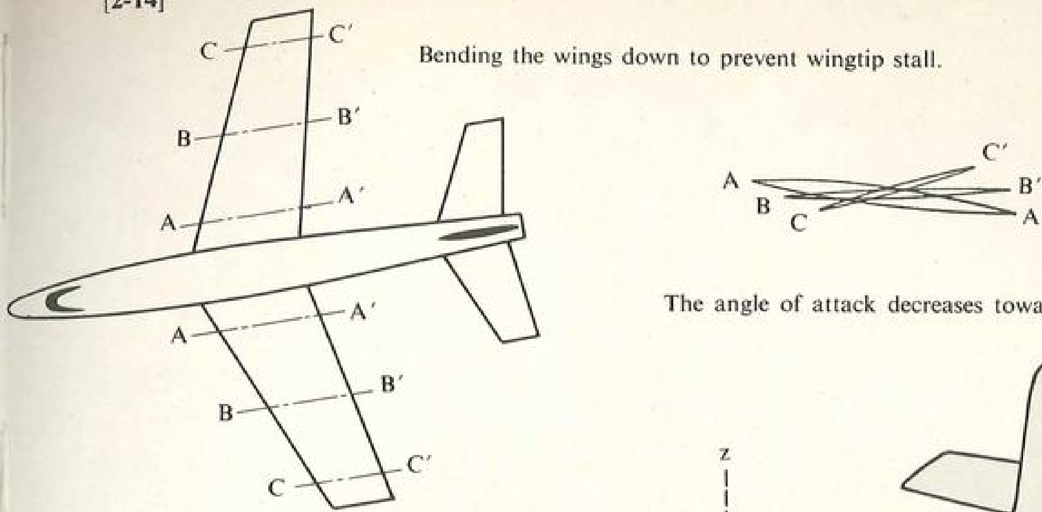
(a) Rectangular wings—even with an imbalance in lift at the wings' bases the plane does not roll.



(b) Sweptback wings—the rolling effect is much greater when the lift imbalance occurs at the wingtips.



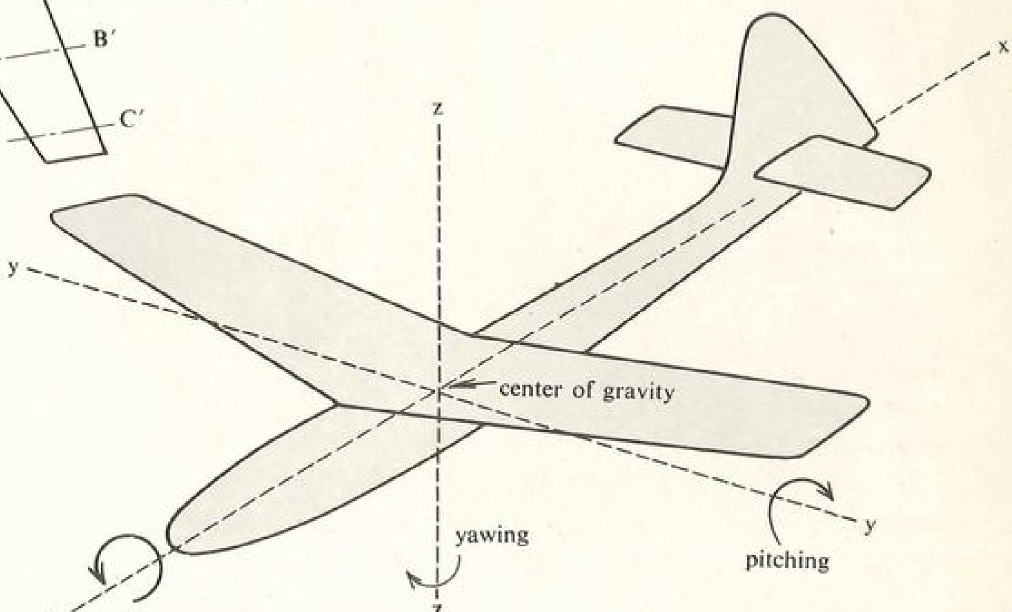
[2-14]




Bending the wings down to prevent wingtip stall.

The angle of attack decreases toward the wingtips.

[2-15]



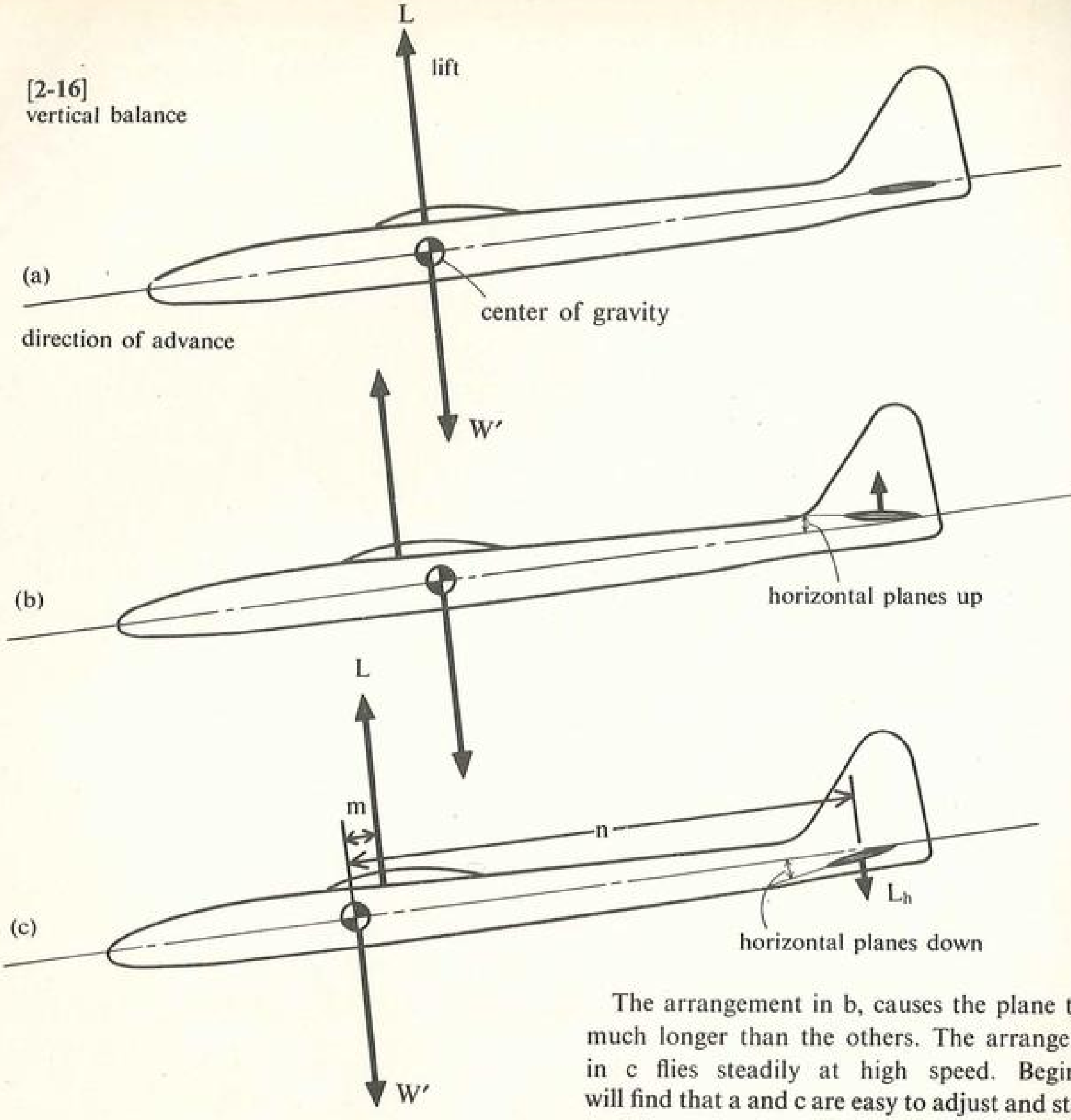

## Motion

Airplanes are capable of many types of motion other than steady flying. If you think of the plane as operating on three axes, all passing through the center of gravity and all intersecting each other at right angles, things will be simpler. These axes are as you see in fig. 2–15. The line running from the nose to the tail is the x axis; movement to either side of it is called rolling. Movement to either side of the y axis, running from wingtip to wingtip, is called pitching. Movement to either side of the z axis, which runs vertically through the center of gravity, is called yawing.

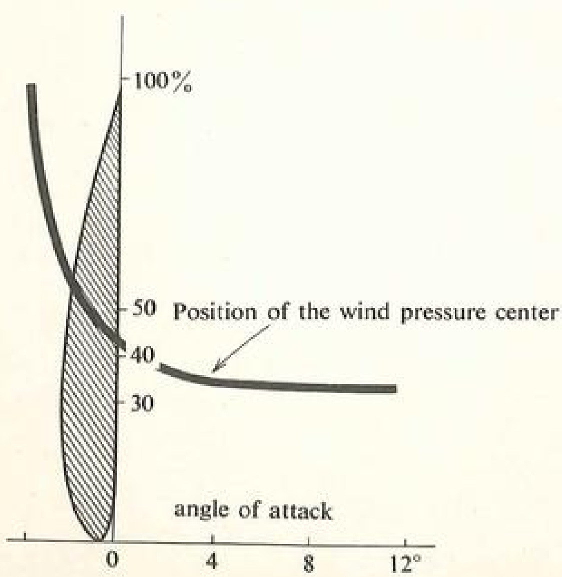
**Longitudinal Balance** Three forces are at work on a plane in glide: lift, drag, and the plane's weight. All three of them are in balance. The only elements that affect the longitudinal balance are those that are at right angles with the plane's direction of advance. Fig. 2–16 shows these elements in normal condition.

A part of the weight of the plane, acting at right angles to the direction of advance, pulls downward. The lift on the wings sustains it aloft. Since the lift operates on a spot about one third of the chord's length back from the leading edge, if we put the center of gravity at that same location, we maintain vertical balance. On the other hand since, as you see in fig. 2–17, the lift center alters with changes in the angle of attack, it is difficult to make the center of gravity and the lift center always agree. We can make up for differences by using the lift on the horizontal tail planes. (See fig. 2–16 b and c.) In b, when the center of gravity, falling behind the center of lift, results in a tail-heavy plane, tip the horizontal tail planes upward to create an upward lift. When, as in c, the center of gravity falls in front of the center of lift, resulting in a nose-heavy plane, tip the horizontal tail planes down to create a downward force ($L_h$). On the basis of the principle of the lever, the following relationships exist between the forces: $L \times m = L_h \times n$. Since n is much longer than m, a slight force is adequate.

[2-16]
vertical balance




[2-17]




Changes in the angle of attack caused by wind pressure center.

The arrangement in b, causes the plane to fly much longer than the others. The arrangement in c flies steadily at high speed. Beginners will find that a and c are easy to adjust and stable. As I have already said, we use the wing chord as a standard in determining the position of the center of gravity. With rectangular wings, we can use the wing chord as it is. With wings of other shapes, we must use the following method to determine the mean aerodynamic chord. We use the following method to arrive at the mean chord length by means of drawings (2–18). Make a sketch of the wing in which $t_t$ is the chord length at the wing tip and $t_r$ the chord length at the wing root. Extend the line $t_t$ by the chord length $t_r$, and extend the line $t_r$ by the chord length $t_t$. Connect the two points at the ends of the extentions with a dotted line. Bisect the original $t_t$ and the original $t_r$, and connect the two center points with a dotted line. The intersection of these two dotted lines will be point M. Draw a line through point M that is parallel to the center line of the plane's fuselage. This line passing through point M will

be the mean aerodynamic chord length $t_c$ of the wing.

Since the flow of air from the main wings heads slightly down, though you attach your horizontal tail planes to agree in direction with the aircraft's direction of advance, in effect they will bend down and amount to the list of a two- or three-degree elevator.

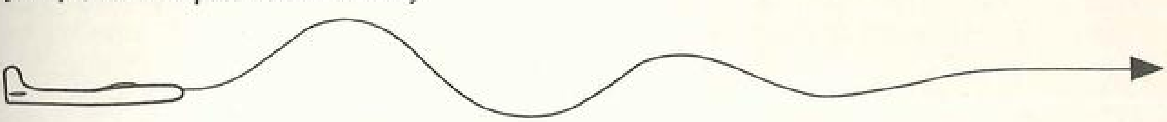
**Longitudinal Stability** In flight, the aircraft may encounter turbulence in the air that will divert it from its balanced flight posture. A plane is stable when it will automatically return to a balanced posture after such an encounter (fig. 2–19 a). A stable craft when, for some reason or another, its nose rises, will return gradually to normal posture; but an unstable craft will pitch worse and worse till it either crashes or stalls (fig. 2–19 b).

To maintain longitudinal stability, once again, we turn to the horizontal tail planes. For instance, should a plane in flight begin to pitch or turn its nose up, increase the angle of attack of the horizontal tail planes. This will increase the lift on the tail section and raise it to bring the airframe back into horizontal posture. The tail will also serve to correct stability if the nose dips. The formula for the area needed to enable the horizontal tail planes to fulfill these functions is as follows:

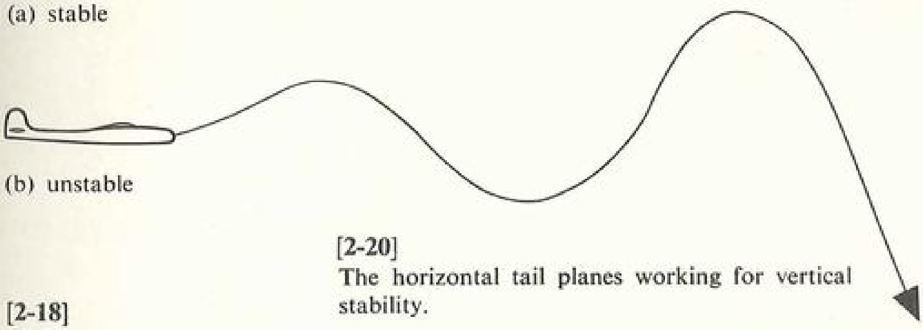
$$S_h = K_h \frac{S \times t_c}{l}$$

When S is the area of the main wings, $t_c$ the mean aerodynamic chord length of the main wings, $l$ the distance from the center of gravity to the center of the horizontal tail plane, and $S_h$ the area of the tail. Since we must make pilotless model airplanes much more stable than real ones, we use $K_h = 0.6 \sim 1.0$. If you move the center of gravity to the rear (fig. 2–16 b), you must enlarge the area of the horizontal tail planes for long, steady flying.

**[2-19]** Good and poor vertical stability

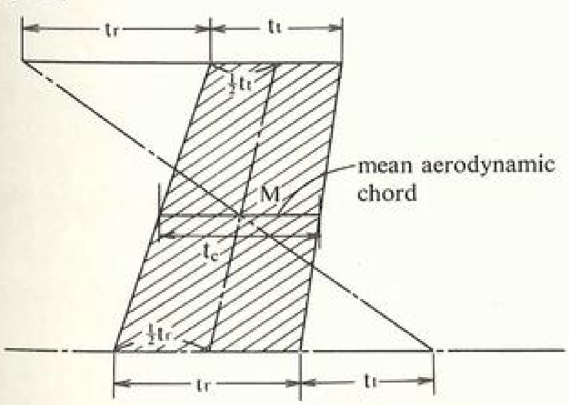


(a) stable



(b) unstable

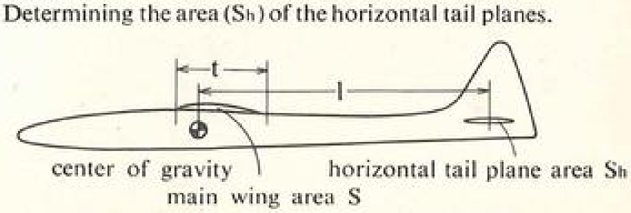
**[2-18]**




**[2-20]**
The horizontal tail planes working for vertical stability.

Should the plane accidentally raise its nose, the horizontal tail planes should be turned up so that the wind striking on the bottom of them will create a strong lift, force the tail up, and bring the aircraft back into the horizontal position.

**[2-21]**
Determining the area ($S_h$) of the horizontal tail planes.



**Lateral Balance and Stability** If your plane is symmetrical it should be laterally balanced, but since the wings will get twisted and out of shape, always carefully straighten them and the fuselage before you send your craft aloft.

Stability, in this case, means the ability of the plane to right itself after deviations in the rolling direction. We can best insure this by adjusting the dihedral angle. Fig. 2–22 shows angles at which wings are attached; the greater the angle the more stable the craft. Should an airplane with angled wings tip over, the lower wing will project a greater surface on the ground below. It will also have a greater lift than the other wing and will, consequently, right the plane.

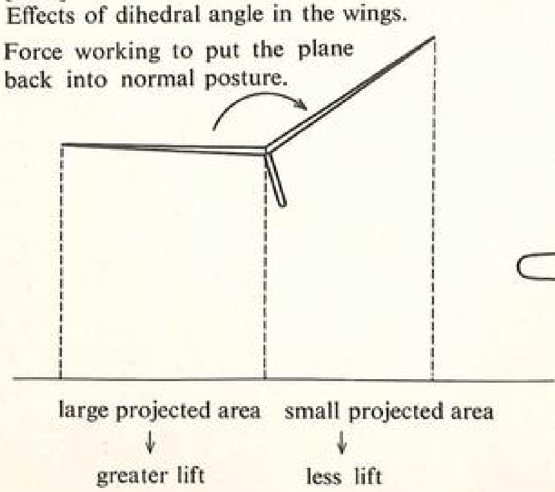
Stability varies with the position of the wings in relation to the height of the fuselage and becomes progressively worse as the wings move farther downward. For this reason the following angles are useful to know:

| Wing Placement on Fuselage | Dihedral Angle |
|---|---|
| High | 5–10 degrees |
| Medium | 10–20 degrees |
| Low | 20–25 degrees |

Sweptback wings have a stabilizing effect similar to that of the upward bend. When you make models with them, the angle of bend can be smaller. I must repeat, however, that the wingtip stalling frequent with these wings renders them unsuitable for model craft.

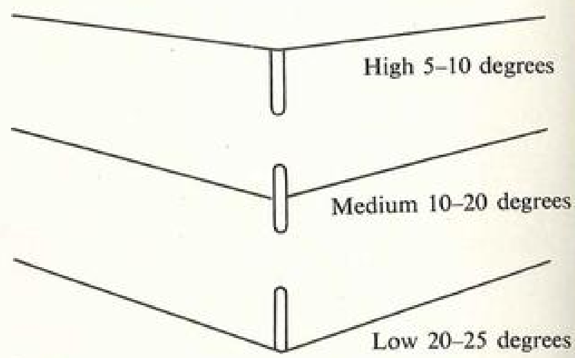
**Directional Stability:** The vertical tail plane is the main factor in bringing back on course an aircraft that yaws. In determining the area of the vertical plane, we take into consideration the main wing areas, their span, the distance from

[2-23]
Effects of dihedral angle in the wings.

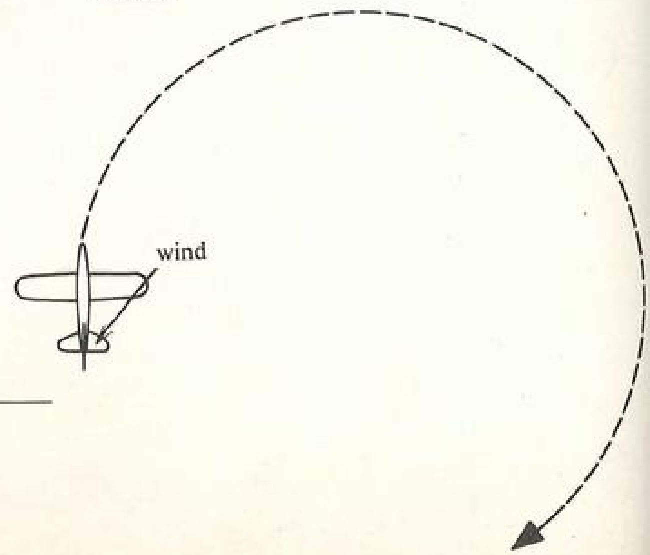


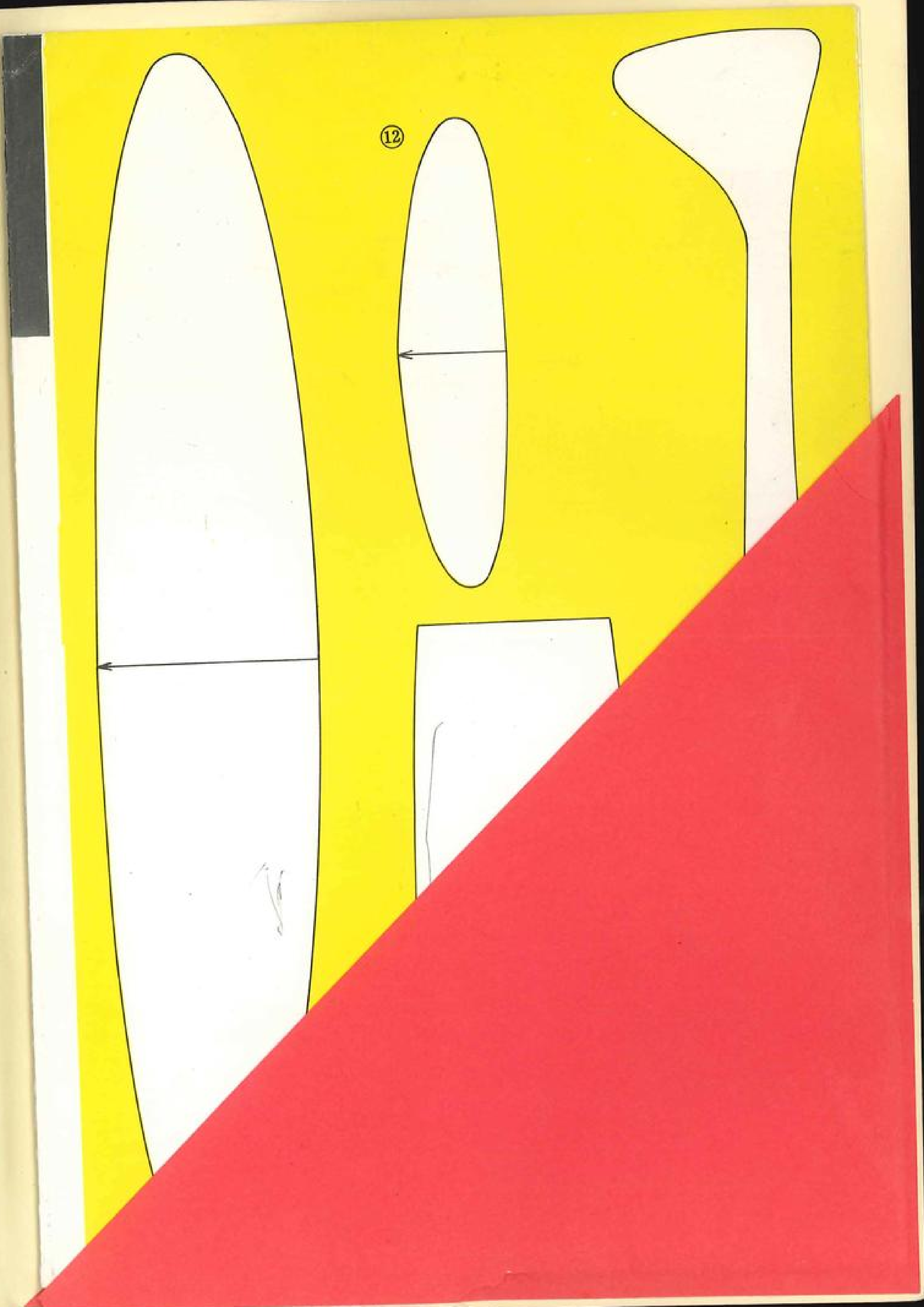

the center of gravity to the center of the vertical tail plane, the dihedral angle, and the side area of the fuselage from the center of gravity forward. For our purpose, suffice it to say that we must make sure that the (area of the vertical tail plane) ×(the distance from the center of gravity to the center of the vertical tail plane) is greater than the (side area of the fuselage from the center of gravity forward)×(the distance from the center of gravity to the center of the side area of the front fuselage section). When the dihedral angle of the wings is great, make the vertical tail plane larger in area. Make it smaller in area when the dihedral angle is small. If the vertical plane is too large, the aircraft will slip to the inside, and go into a spiral descent. If it is too small, the tail will wobble. All this means that you must make several experiments, taking into consideration the upward bend of the wings, to determine the best area for the vertical tail plane.

[2-22]
Wing placements and suitable dihedral angles.




[2-24]
When the vertical tail plane is too large, the aircraft will slip to the inside and ultimately go into a spiral descent.

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